Television Handbook

for the amateur

BIAGIO PRESTI

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Television Handbook for the amateur

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CONSTRUCTION PROJECTS
TV THEORY
SPECIAL CIRCUITS
MONOCHROME TV
COLOR TV

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Foreword

The author wishes to express his gratitude to Ronald Adamson (WA9YJZ), V.P. Aptron Laboratories, who generously and graciously assisted in the preparation of this book. Without his constructive suggestions regarding the content included specifically from the point of view of the experienced amateur, this book would not have been possible.

About the Author

Biagio Presti has been working in the television field since 1949. He is General Manager of the Broadcast Equipment Division of Sarkes Tarzian, Inc. and President of Aptron Laboratories. He has authored numerous articles on television and microwaves and holds several patents. He was responsible for pioneering the use of solid state switching in broadcast television, digital special effects, and computer automation switching now in common use throughout the broadcast industry.

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Introduction

The amateur is constantly challenged by the evolving electronic technology changes. Fast Scan Television encompasses a wide variety of this technology including, AM modulation, FM modulation, suppressed carrier, single sideband, phase and quadrature modulation, low pass and high pass filters, delay lines, aperture circuits, pulse generating and separating circuits, bandpass and wide band circuits, timing, gating, gamma correction, clamping, and computer circuits, and even audio circuits.

The emphasis in this book is to bring together a wide variety of circuits used to create, transmit, and receive the television signal (including Color television). The theory of operation and purpose for each circuit is discussed in down-to-earth language with minimum use of mathematics and with numerous illustrations.

A separate section is included for special circuits not commonly found in the more simplified TV equipment, but of interest to the more dedicated amateur; and a special section on an actual TV transmitter and receiver used for ATV is included discussing design parameters and principles.

TELEVISION SYSTEM FUNDAMENTALS

Television System Fundamentals

General

Monochrome, or black and white, television transmits essentially two pieces of information. These are brightness variations of the televised object and synchronizing information.

Brightness variations are conveyed by amplitude modulation of the picture or video RF carrier. When detected in the receiver, these amplitude variations appear at the kinescope or picture tube grid as voltage variations which produce electron beam intensity modulation and thereby vary the intensity of the phosphor emission of light in the kinescope tube as it scans across the face of the picture tube.

The synchronizing pulse information is combined with the brightness information prior to transmission. Both vertical and horizontal sync pulses are transmitted and these are detected in the receiver by a waveform separation technique. After the vertical and horizontal synchronizing pulses are detected they are used to sync lock the internal freerunning vertical and horizontal oscillators in the receiver which produce the scanning action of the picture tube electron beam. These circuits then serve to cause the transmitter signal and receiver scanning to be time coincident. Figure 1 is a block diagram of the simple television system. The TV camera creates an electrical analog of the scene brightness variations and

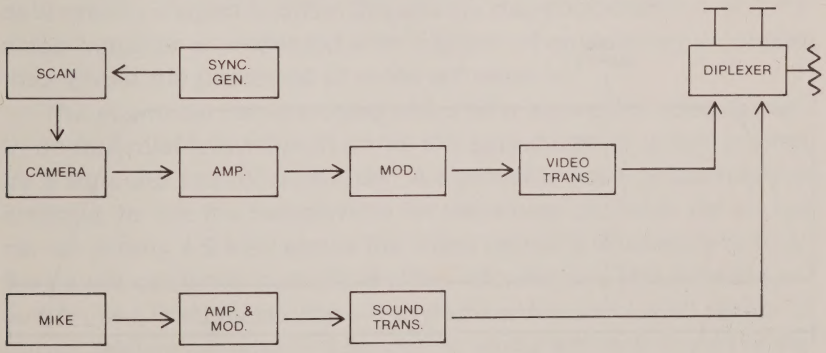


Figure 1

this signal is impressed on the transmitter RF carrier. The signal transmitted contains both brightness and synchronizing data which when received and detected at the receiver produce a corresponding brightness variation at the picture tube and the original scene is reproduced to the viewer's eye. The television camera is analogous to the microphone used in sound transmission. Because pictures contain substantially more detail to be transmitted the bandwidth of frequencies required is much greater than for the transmission of audio signals. Audio frequencies required for faithful reproduction of voice frequencies can be limited to 3000 Hz; for reproduction of high fidelity music, 15,000 Hz. But, for faithful reproduction of picture information several megahertz of bandwidth is needed.

In the standard television broadcast system an RF channel of 6 MHz is allocated for the transmission of television pictures. Before going into more detail of the characteristics of the television transmission channel it is well to remember that in sound transmissions, or any transmissions where an RF carrier is modulated, two sidebands are created in the modulation process. Both sidebands contain the intelligence being transmitted and one can use only one of the sidebands to recover the information. The essential significance of using one of the sidebands is that the amount of recovered energy at the receiver detector is reduced to half that which would be recovered if both sidebands are transmitted and detected. The television signal is single sidebanded in a special way so that the spectrum space required for transmission is reduced to conserve valuable spectrum space and allowing more channels to be contained in a given spectrum space. The special sideband for the television signal is called vestigial sideband.

Figure 2 illustrates the makeup of the standard US television

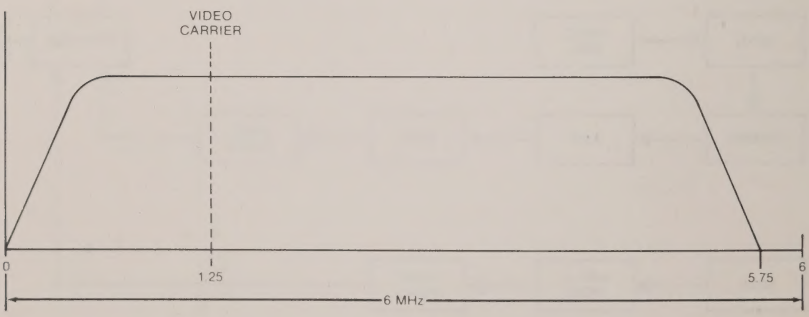


Figure 2

channel RF spectrum. The lower sideband is suppressed beyond 1.25 MHz while the upper sideband is fully transmitted up to approximately 4.2 MHz and gradually rolled off to a limit of 4.75 MHz. So the television signal is double sideband up to 1.25 MHz and single sideband beyond 1.25 MHz. The television sound carrier is located 4.5 MHz above the video carrier and it is FM modulated to a limit of ± 25 kc (as opposed to standard FM broadcast modulation of ± 75 kc). The television picture modulation has a spectrum of 4.2 MHz to use for the video information to be transmitted.

This video bandwidth limitation results in a limitation in the number of 'picture elements' which may be transmitted and establishes the maximum 'resolution' of the transmitted picture. The resolution or detail of the transmitted picture is limited to approximately 200,000 picture elements. (See page 39)

With the understanding that the limitation in video bandwidth comes a limitation in maximum resolution or picture detail one should not assume that there is no point in having higher resolution video signals than the system will eventually pass. The reason for this will be covered later in detail, however, suffice it to say now that the energy content of the higher frequency components of the picture is far lower than the low frequency components and there is a real advantage in starting with a wide band video signal.

Again, referring to Figure 2, we see that the lower sideband is not totally eliminated but is transmitted up to 1.25 MHz. In other words, the signal is double sideband to 1.25 MHz, and single sideband above 1.25 MHz. Since the detected signal at the receiver will have twice the energy up to 1.25 MHz, one would expect twice the voltage output from the 2nd detector for these frequencies. This would indeed occur except for the fact that the TV receiver IF response is deliberately shaped to offset this energy step characteristic, and the video detector is presented with a signal of equal energy content throughout the passband of video information.

The sound carrier is located at 4.5 MHz above the video carrier. In commercial television systems the sound carrier is transmitted by a separate sound transmitter. A diplexer is used, preceding the antenna, to mix the two carriers for transmission. Since the sound carrier is only 4.5 MHz above the video carrier it is possible to treat the sound carrier as part of the video information. This type of system is used in many microwave systems where the sound carrier is transmitted on a modulated subcarrier along with and as part of the video information. It is also possible to treat the audio modulation in

other ways, such as digital modulation during sync interval, or FM modulation of the video carrier, etc., however, such systems prevent the use of standard TV receivers which remove the sound carrier by an intercarrier demodulation method. These points will be discussed later in more detail.

The following pages begin a more detailed discussion of the operation and theory of the several component systems and circuits which are used in television systems.

The Scanning Process

Table I is the detail specification standard for US Monochrome television. To fully understand how the video signal is created we must first understand the scanning process. Figure 3 illustrates the principle involved in scanning the electron beam (in the pick-up device or receiving device) across and down to produce what is called the television raster. There are a total of 525 lines of scanning in the US television system. (Other countries use slightly different scanning rates and therefore have a different number of scanning lines in a raster.) The original premise of scanning was based upon using 60 Hz for the vertical rate which corresponds with the 60 Hz power system in the US, and the system concept was developed to include interlaced scanning techniques wherein alternate 'fields' of the raster were caused to fall between each other to improve vertical resolution. This means that 262½ scanning lines would appear in the first $\frac{1}{60}$ second and then the beam would be returned to the starting point, offset by ½ line, and 262½ scanning lines would be caused to fall between the area of the first field scanning lines for a total of 525 lines in $\frac{1}{30}$th second. Well 525 X 30= 15750 Hz which is the horizontal scanning oscillator rate. Due to the frequency relationship of the horizontal and vertical oscillator rates the last line of the first field of scanning lines ends in the middle of its horizontal motion, is brought to the top of the raster and starts from the middle of the top line of the second field, and ends at the bottom of the raster at the bottom right corner of the raster. It is immediately ob-

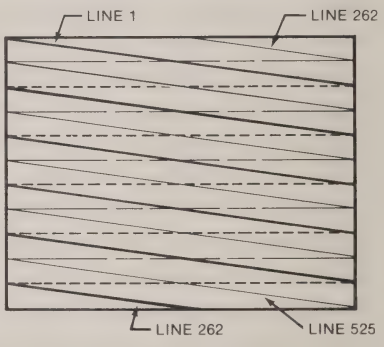


Figure 3

vious that the horizontal and vertical oscillators must be locked in a related way for the two fields to properly interlace where the first set of scanning lines and second set of scanning lines interleave producing the interlaced scanning action. If these two frequencies are not locked together they will drift relative to each other and random scanning, pairing of lines, etc., will result in random interlacing greatly reducing vertical resolution or detail. Figure 4 is a pictorial of

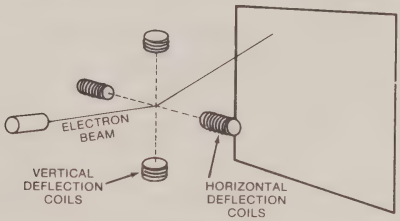


Figure 4

the principle used to cause the electron beam in a pick-up tube or kinescope to scan. The beam is deflected, usually by a magnetic field, from left to right by creating a sawtooth current in the deflection coils. This sawtooth current changes in a linear manner so that the rate of change in position of the electron beam is linear. The vertical deflection is at a much slower rate than the horizontal (60 Hz compared with 15750 Hz) so the beam is pulled downward slowly as it traverses its scan horizontally. At $\frac{1}{60}$th second the beam is at the bottom of the screen and 262$\frac{1}{2}$ lines have been scanned horizontally. At the end of each individual horizontal scan the beam is brought back to the left side by the action of the sawtooth current as shown in figure 5(a). Likewise at the end of the vertical scan the beam is brought up to the top. During the time the beam is being returned the electron beam is turned off by an action called 'blanking' which is associated only with the electron gun and does not affect the deflection current or the resulting magnetic field. Figure 5(b) shows the relationship of the video electrical signal and the sawtooth causing the scanning action.

Figure 5(a)

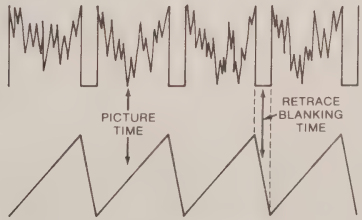


Figure 5(b)

The Video Signal Processing Steps

In the following section the generation and processing of the video signal is discussed. The video signal may be created in various ways, as with a flying spot scanner, Plumbicon or Vidicon camera system, from live or film pickup, etc. However, the basic processing stages used to produce the final composite video signal are essentially the same.

Using a video signal generated from a television camera as an example, requires that the pick up tube be 'scanned', the electrical signal so generated to be 'blanked', 'clamped', 'aperture corrected', 'gamma corrected', and synchronizing pulses added. Many simplified cameras do not necessarily perform all of the possible processing steps. Many exclude white clipping or gamma correction for example, however we will touch upon most of the processing steps in this section.

An example of how a video signal is generated can be best illustrated by examining the operation of the Vidicon tube. Figure 6 illustrates pictorially the construction of a Vidicon tube and its associated deflection and focusing coil. There are many types of Vidicon tubes and various sizes as 1", ⅔", ½" etc., as well as magnetically focused or electrostatically focused or combinations of these focusing and deflection schemes, various phosphors and persistence, special purpose as xray, etc. However, the operation of these tubes is essentially the same. Referring to Figure 6, the cathode is the source of the electrons which form the electron beam. Grid 1 is

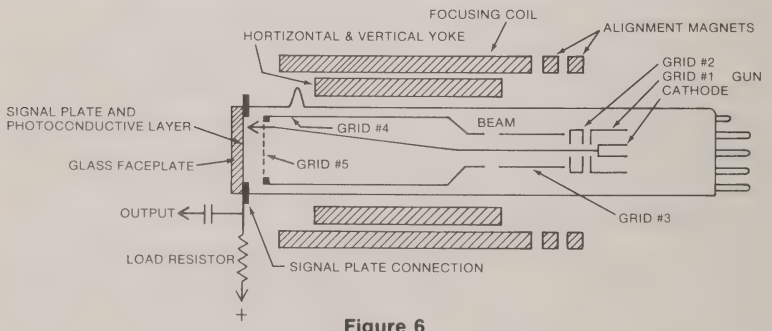


Figure 6

a tubular element concentric to the beam and controls the quantity of electrons, or the beam intensity. Grid 2 is a tubular element which accelerates the beam toward the target, and Grid 3 is a tubular element which operates in conjunction with the external focus coil to

concentrate the beam into a narrow focused electron stream coming to focus at the target. Grid 4 & 5 is a screen mesh mounted at the end which is used to decelerate the beam and assures that the beam strikes the target perpendicularly . . . this screen also collects any excess electrons not attracted to the target.

The photosensitive element is generally made up of two layers and bonded to the faceplate glass of the tube. The layer directly adjacent to the faceplate glass is a transparent coating which is conducting material and becomes the signal electrode of the Vidicon. Deposited on top of this transparent signal electrode layer is a thin layer of photoconducting material the inner side of which is the target element of the Vidicon. A positive voltage is applied to this electrode to attract the electrons forming the beam. The combination of the layer forming the signal electrode and target electrode photoconducting layer form a capacitor which acts as a 'leaky capacitor' at each point where the electron beam strikes the target. In other words the target can be viewed as a large number of small capacitors side by side all over its surface with the signal electrode side being tied to a common point and the target side floating and exposed to the electron stream. The dielectric of these myriad capacitors is the photoconducting material itself. The properties of the photoconducting material are such that when light strikes the surface the resistance of the material is reduced in proportion to the amount of light intensity. This has the effect of creating the 'leaky' capacitance where the amount of leakage is proportional to the light falling on the signal electrode side of the capacitor. Figure 7 diagrams a small section to illustrate the operation. The diameter of the electron beam is such that it would cover many small elements of capacitive sections on the target as opposed to only one used in the

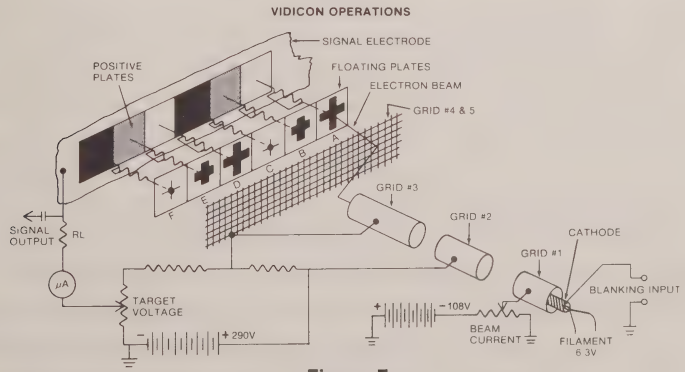


Figure 7

figure 7 to illustrate the operation, but for the purpose of analyzing the operation of the Vidicon we will consider each small element as being scanned by the beam one at a time. We will assume that the light image consists of a series of black, grey, white elements. Where the image is black the resistance of the photoconductor is very high. Where the image is white the photoconducting material has very low resistance. Where the white areas exist the target electrode positive potential attracts many electrons from it and leaves this area highly positively charged as a result. This is illustrated in Figure 7 by a large + sign on the photoconducting side of the target element. Where the grey image areas exist the number of free electrons attracted to the positive target potential is less and therefore leaves somewhat less positive charge, and where the light image is black, i.e. no light falls on this portion, the charge of the portion represented is essentially zero. This action of forming a myriad of small leaky capacitors (see figure 8) of varying resistance proportional to the amount of light present on each element produce varying amounts of current flow in the signal electrode which is proportional to the amount of light at given points. In the black areas no change in resistance occurs and the actual resistance is the static resistance of the photoconductor material. However some current will flow and this is called the dark current of the Vidicon. The signal polarity across the Vidicon signal electrode load resistor is positive going for the low light areas and negative going for the high light areas.

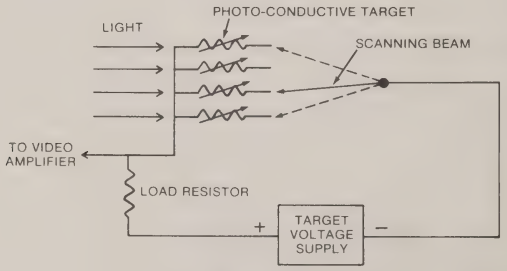


Figure 8

Any given element of the surface is scanned by the electron beam once for each frame (or two fields) every 33,000 μsec and the charge on the floating plate builds up between successive scans, is discharged by the passing of the beam which replenishes or neutralizes the element each time it passes. As electrons are added to the element, other electrons are driven off the opposite side by electro-

static force and it is these electrons flowing through the signal electrode load resistance which become the signal voltage representing the electrical analog of the optical image impressed on the faceplate of the Vidicon. Because of the relatively large charge in the high light areas (white) the amount of current required to discharge the element is large and therefore a larger current flows through the load resistance. Figure 9 shows the circuit schematically. Properly adjusted the Vidicon will produce approximately .3 μamp in the high light areas and as little as .02 μamp (dark current) in the low light areas. The difference between the dark current and the total current is the useful signal current. As can be seen in Figure 9, the output load is attached to the signal plate and the voltage across the resistor is 'white negative'. Generally, Blanking pulses are applied to the

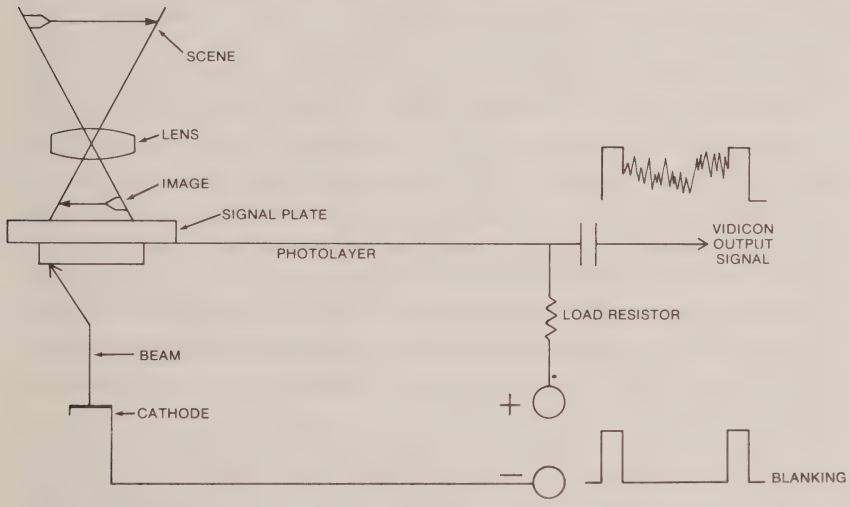


Figure 9

Vidicon cathode to turn off the electron beam during retrace time of the scanning beam. Usually the pulse shape at the output of the Vidicon is not quite so clean as shown on the figure and the signal voltage requires some processing in the following amplifiers. The best signal to noise ratio from the Vidicon is a function of several factors. The light level is most important and depends upon the depth of field needed which is determined by the lens f stop. The more depth of field required the more the lens must be stopped down and therefore more light is needed on the scene to be televised. Good signal to noise (S/N) will be obtained by keeping the highlight signal current between .15 and .3 μamp.

Resolution, or picture detail, is primarily a function of beam diameter and focus, and amplifier bandpass characteristics. Because of this it is important that the beam current be just sufficient to discharge the scene highlights since increasing beam current generally results in beam spreading and loss of resolution. If scene highlights cannot be discharged due to bright spots, specular reflections, etc., one must eliminate the highlight spot or stop the lens down. It is wise to keep the ratio of high light to dark areas (contrast ratio) of the scene less than 15-1 or better yet, 5-1 . . . in other words keep the scene lighting as flat as possible over the area of interest. Generally light levels of 100 ft. candles is adequate on the scene. If the light level is too low the Vidicon output signal will be too low which can only be increased by increasing preamplifier gain which will introduce more noise, or by increasing target voltage which will increase the dark current again degrading the S/N. Increasing the target will also increase the 'lag' which will cause highlights to smear particularly where movement is present. Lag results when the individual elements represented by the small capacitors described before cannot be sufficiently discharged during the time the beam is passing over the area. As a result some of the previous field charge is present in the next passover by the beam. In summary, to obtain best performance from the Vidicon, keep scene illumination high, keep lens setting stopped down consistent with light level and depth of field required, set target for proper signal current, keep beam current at minimum level to discharge highlights, and make sure lens is properly focused.

As stated above the beam size or diameter has an important effect on the ultimate resolution capability of the Vidicon. There is another effect resulting from the beam diameter which can only be reduced to a finite minimum. This effect is called the aperture effect. Due to the finite size of the beam the smallest picture element which will produce any signal current also has a finite dimension. There are really two separate effects resulting from the finite beam diameter. Figure 10 is an illustration of the electron beam passing through picture elements. In figure 10 a representation of the picture elements comprised of alternating black and white picture element squares is shown along with the ideal reproduced waveform and the actual waveform, which results from the finite beam diameter, shown below. The rounded edges in the actual waveform results from the fact that the current rises slowly rather than abruptly as the beam enters the picture element area. The effect is

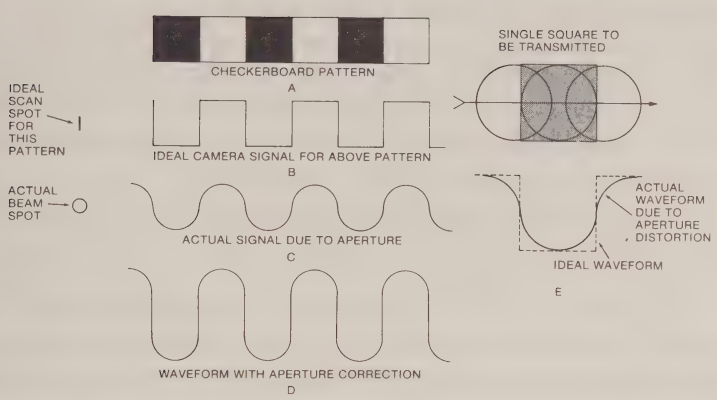


Figure 10

exactly like that which results from poor frequency response for a square wave passing through an amplifier when the higher frequency components are attenuated. The second aperture effect is an amplitude response effect. Figure 11 illustrates this effect. In this representation the size of the alternate black and white picture elements become smaller and smaller. As the picture element scanned becomes smaller the amount of time the beam spends in the element is less and the amount of current produced from the element is less resulting in a lower amplitude signal. Obviously, at some point, the element becomes smaller than the beam diameter and produces no current. So, we have two concurrent effects resulting from the finite beam diameter; poor apparent frequency response and poor amplitude response as the picture element size reduces. The amplitude vs frequency response resulting solely from the aperturing effect is shown in figure 12. The larger picture elements representing the low frequency components of the scene have greater output

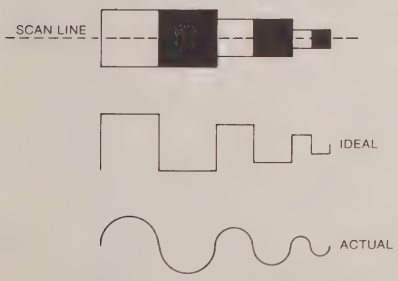


Figure 11

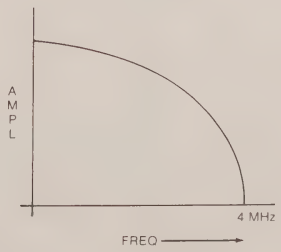


Figure 12

than the smaller picture elements which represent the high frequency components, or detail, of the scene.

In addition to the inherent characteristics of the Vidicon we have a more common effect resulting from the high impedance of the Vidicon target and stray capacitances associated with the target capacitance coupled with the output lead capacitance to the 1st preamplifier and the preamp input capacitance.

The 1st preamp plays a dominant role in contributing most of the noise in the video signal as well. Some designs use a preemphasis network between the target and 1st preamp and a later deemphasis network following the 1st stage (similar to the FM concept) to increase the level of the high frequency components emanating from the Vidicon before amplification and noise is introduced by the 1st preamp.

A damped inductance, self resonating around 8 MHz is common, as the preemphasis element and a series resonating coil-capacitor to ground in following stages is used as the deemphasis network. The 'Q' of these devices is made deliberately low to avoid any ringing characteristic.

More commonly, a simple 'hi-peaker' circuit is used following the 1st preamp as shown in figure 13. The hi-peaker usually consists of a transistor stage with a large emitter resistor to provide degeneration bypassed by a variable capacitor of low value. At the R-C crossover the signal gain will rise rapidly, perhaps by 2 db per octave. Depending upon the setting of the trimmer capacity the time constant can be set to almost exactly offset the frequency response droop giving an overall flat response.

In the absence of any bypass capacitor the amplifier is degenerative to the extent that the emitter signal voltage opposes the

Figure 13

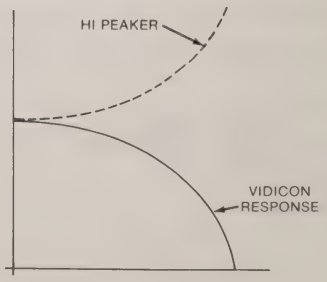


Figure 14

input signal . . . if a small value capacity is placed across the emitter resistor the amount of degeneration will be a function of frequency. The value is picked so that the parallel value of X_C and R of the emitter circuit will increase the amplifier gain (through less degeneration) as the frequencies of the signal go up. Figure 14 is an example of the action of the capacitor/resistor combination on the amplifier gain. At low frequencies the capacitor X_C is very high and has little or no effect on the degeneration, however as the frequency increases the X_C decreases bringing the emitter more and more toward AC ground potential and thereby decreasing the degeneration and increasing the amplifier gain as a function of frequency. This kind of circuit, while simple and low cost, has the characteristic of rotating the phase of the higher frequency components of the signal relative to the low frequency components of the signal. This phase change will cause white edges to appear on the signal transitions, particularly where there is rapid rise times, as in detail areas of the picture and the sync and blanking areas, where pulse type signals are present.

To better understand this effect and the principles of more sophisticated aperture correction circuits it might be well to review the basics of a square or pulse wave characteristics.

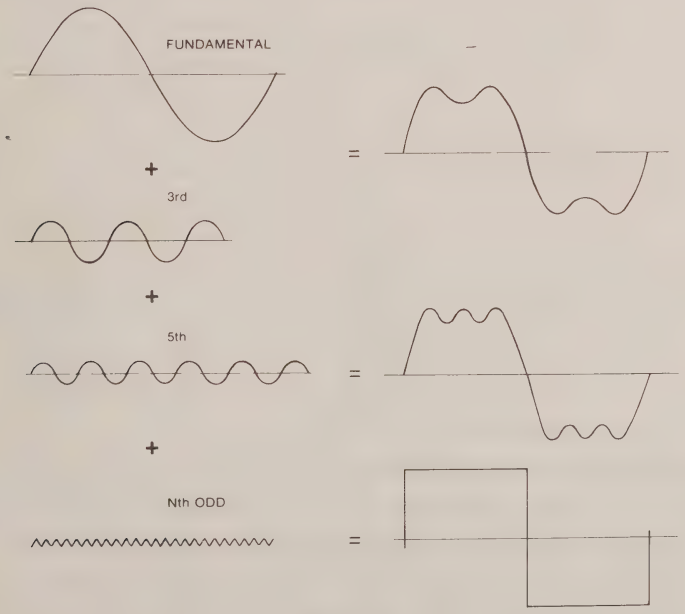


Figure 15

One way to analyze a pulse is to think of their being made up of a fundamental sinewave and odd harmonics of the fundamental. Figure 15 illustrates how a square wave is made up from sinewaves which add together to create the steep rise and fall times of the transitions and the squared off top of the wave.

Viewing the square wave this way quickly allows one to see how high frequency phase shifts and amplitude changes modify the characteristic of the squarewave.

Figure 15 shows that if the higher frequency components are deleted entirely the squarewave becomes more sinewave in appearance. This rounding off would occur if the signal is passed through an amplifier with limited high frequency response and is directly analogous to the aperturing effect which occurs in the Vidicon discussed previously.

The leading and trailing edges contain the high frequency components of the signal. When the higher frequencies are attenuated the edge begins to slope. Figure 16 illustrates the result when higher frequency components are simply shifted in phase relationship to the fundamental, as occurs when a simple hi-peaker circuit is used.

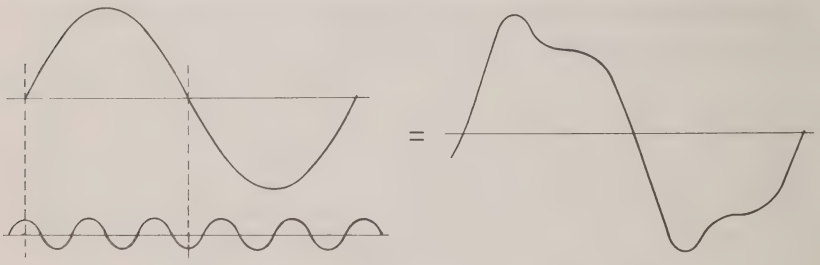


Figure 16

As the higher frequency components are slightly delayed relative to the fundamental they add sooner than normal and emphasize the transition edge producing a spike overshoot at each transition.

To offset some of the disadvantages of a simple hi-peaker correction circuit a feedback amplifier may be used which is designed to alter the frequency response as a function of frequency. Figure 17

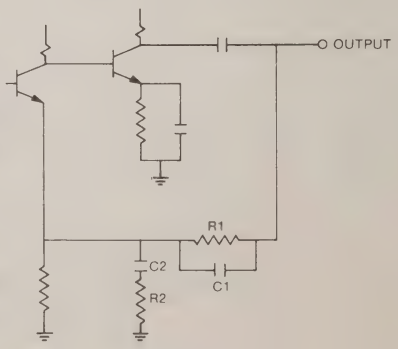


Figure 17

is an example using a feedback pair where the feedback loop includes R1C1 and R2C2 configured to provide increasing feedback with increasing frequency which tends to linearize the response of the system. The phase angle remains relatively constant as the feedback increases.

A much better and more sophisticated aperture correction circuit utilizes delay lines and a complete discussion may be found in the special circuits section of this book.

Gamma Correction

The Vidicon signal current output is not a linear function of the light input, nor is the light output of the receiver kinescope a linear function of voltage input. As a result there is not a one-to-one correlation between the televised scene and the final reproduced picture unless some process is used to linearize the system. That's where gamma correction comes in.

A Vidicon has a gamma (i.e., light input vs signal output) of typically .6. Typical picture tubes have a gamma of 2.2. Since the objective is to achieve a gamma of 1, a straight line, we would like the gamma of the Vidicon to be the reciprocal of the picture tube, or 1/2.2 = .45.

As shown in figure 18, if the system is linear we have a straight line transfer characteristic. This would occur if the Vidicon had a

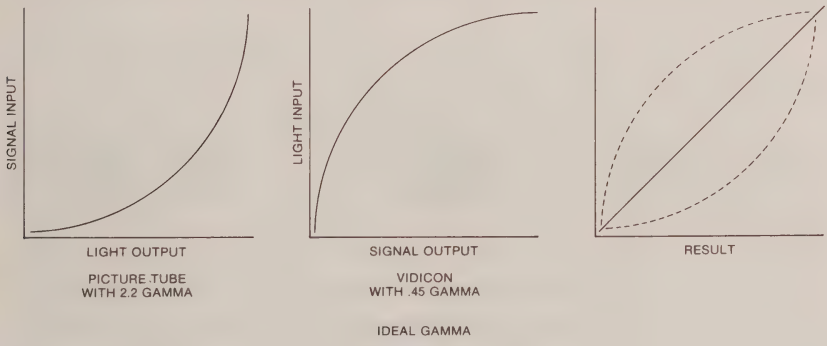


Figure 18

gamma of .45. We can modify the gamma or transfer characteristics in processing the video signal as shown in figure 19. This circuit is a simple form of gamma correction where the signal gain of the amplifier is decreased as the signal rises toward white level. The diodes become conductive at different levels due to the biasing arrangement via the resistor divider. As the signal reaches the different con-

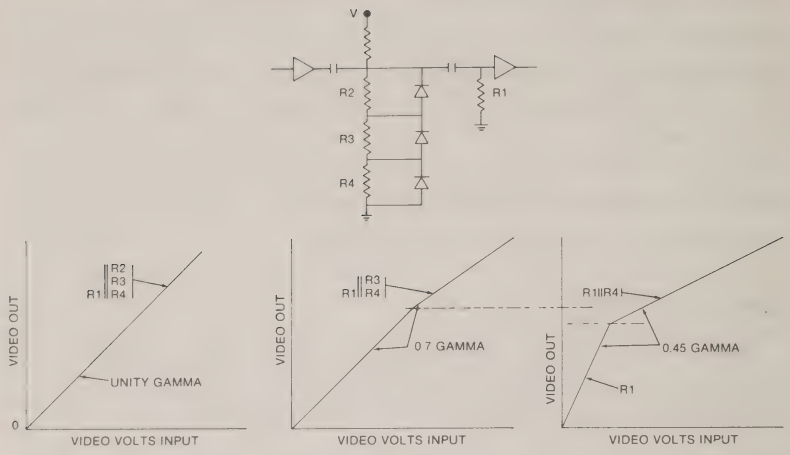


Figure 19

duction points of the diodes the diodes shunt the corresponding resistor reducing the load impedance accordingly and the video level is reduced proportionately. Figure 20 shows the results on a staircase signal.

Video Signals

It is important to become familiar with the appearance of the video signal as it is displayed electrically on an oscilloscope.

Figure 21 illustrates a monochrome video signal, shown at the horizontal scan rate. During the picture portion of the video the signal excursions from Black, to Grey, to White occur as a function of the televised scene. Generally there is not a single line trace in this area due to the scene content and the resulting mixture of many shades in the scene. Figure 22 illustrates how the video would appear if the camera were looking at all black figure 22 (a), all grey figure 22 (b), or all white figure 22 (c). Figure 22 shows these as consecutive lines for convenience and comparison.

Figure 23 illustrates the resulting signal if the scene were all black except for a white bar from top to bottom in the center of the scene or located at differing positions across the scene. Likewise figure 24 illustrates an all white scene with a black bar at different locations across the scene.

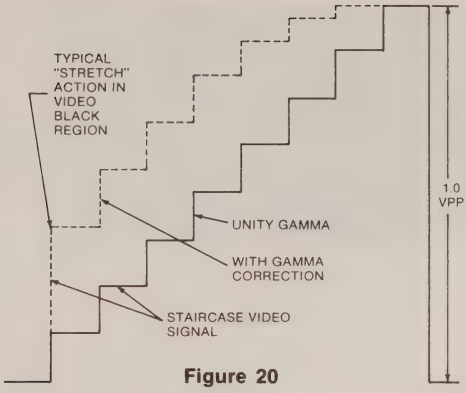


Figure 20

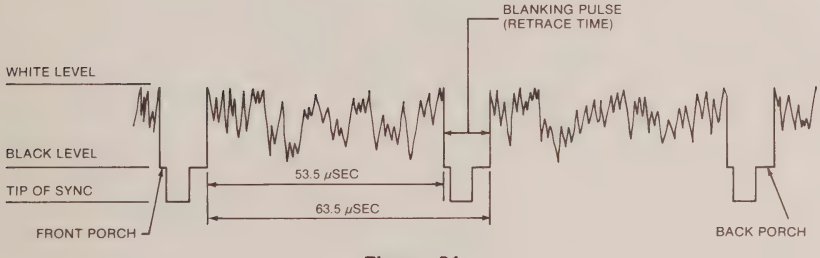


Figure 21

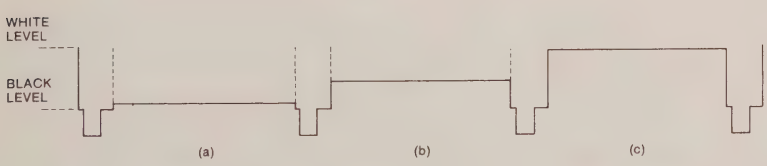


Figure 22

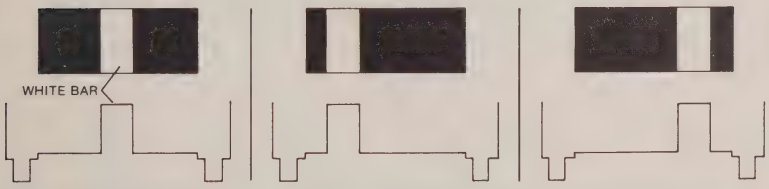


Figure 23

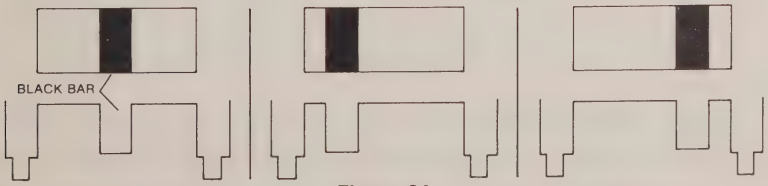


Figure 24

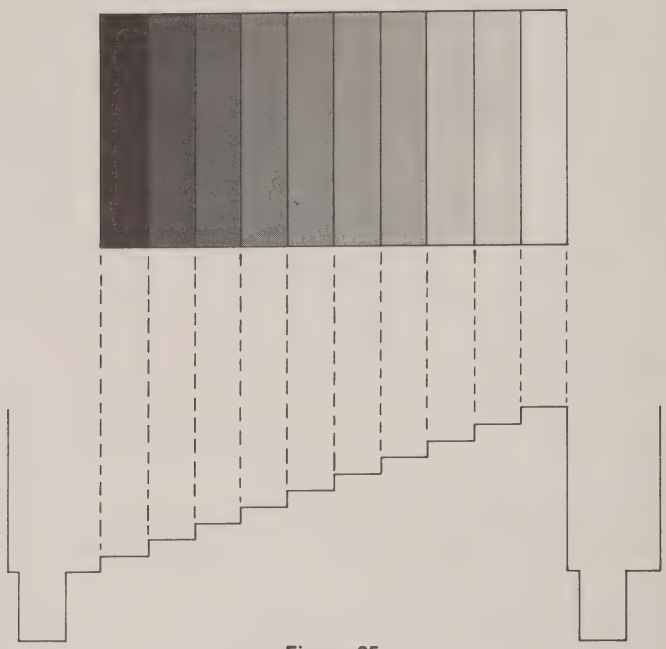


Figure 25

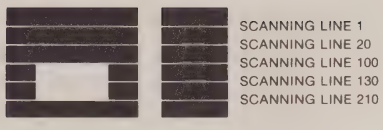
Figure 25 illustrates the video signal resulting from viewing a grey scale pattern ranging from black to white level from left to right.

One final example, in figure 26, which illustrates the result when the scene consists of a white window and white bar and shows what various horizontal scan lines would produce at various parts of the scene as it is scanned from top to bottom. The example takes arbitrary line numbers to illustrate the point. Also actual displays on an oscilloscope are not usually as clean cut as the illustration portrayal.

Clamping

Because the picture content will vary as a function of the scene content the 'average' level of the signal will vary accordingly. For example, a pulse or square wave type signal as shown in figure 27 will have a different average corresponding to the 'duty cycle' of the squarewave.

A video signal has the same characteristics as shown in figure 28. This APL (average picture level) variation would be undesirable since the background level of the reproduced picture will vary



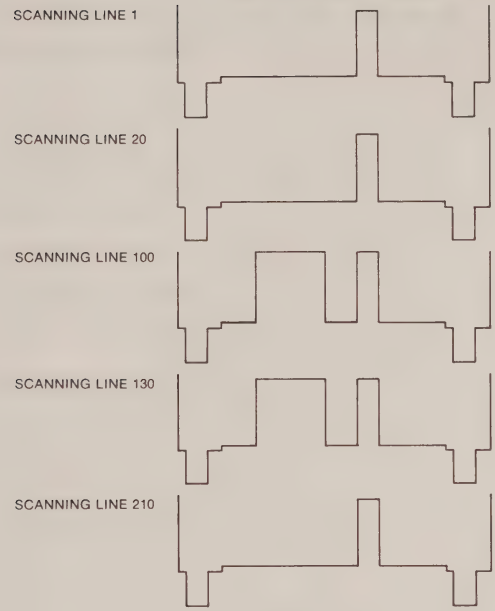


Figure 26

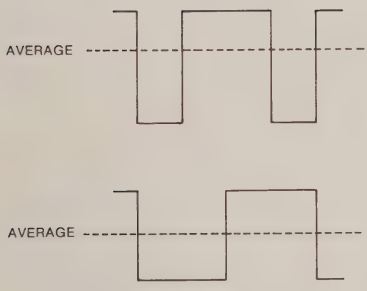


Figure 27

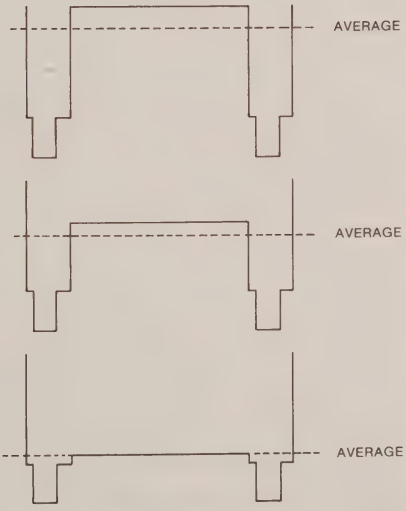


Figure 28

giving washed out or over contrasty pictures. To correct this, clamping of the video signal to a reference is required. The reference used is logically the part of the signal which remains constant regardless of scene content such as the sync tip or 'black level' which is the point where the blanking pulse and sync pulse meet. (The various names which are applied to the video signal portions is shown in figure 21).

The most simple form of 'clamping' is DC restoration using a diode clamp. This is a passive circuit which relies upon the ratio of the diode resistance when conducting vs the high value of R when the diode is nonconducting as shown in figure 29. The RC time constant of this configuration is either very high or very low as a function of the diode conduction. If a pulse is presented to this circuit it will either clamp to the top or the bottom of the pulse depending on which polarity the diode is placed.

On the initial pulse the diode rectifies a small part of the peak negative going portion of the signal (figure 30), when the conduction point of the diode is reached, and quickly charges the capacitor C, until the signal is clamped to the most negative portion of the signal. The driving circuit should be a low impedance type circuit, as an emitter follower, since it is part of the charging path, and the value of R should be high enough so that the RC time constant is long relative to the period of the input signal. If a bias voltage is introduced between the diode and ground, the reference point of the clamp is changed to the value of the bias. Usually a small portion of the most negative portion of the signal is clipped or compressed by the diode clamp action and for a TV signal one may want to stretch the sync signal slightly to compensate for this compression. If the diode is reversed, then the clamping action occurs on the positive peaks. By clamping the video signal in this way low frequency variations, as hum, are effectively removed from the signal.

A little better clamp for TV signals is shown in figure 31. Since the point which is of interest for referencing the TV signal is at sync tip or black level it is desirable to have a clamp which operates during the blanking-sync interval.

By providing a clamping signal to the transistor Q2 (which can be a sync pulse) the capacitor C is charged during retrace time of the scanning time by forcing Q2 into heavy conduction during this interval. In this kind of circuit the right side of C is brought to ground, or 0 Volts, and when the clamping pulse is gone, Q2 is nonconducting and a very high impedance. Q3 must have a high input impe-

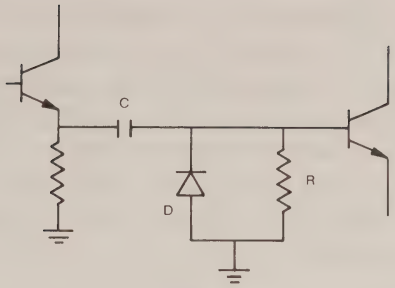
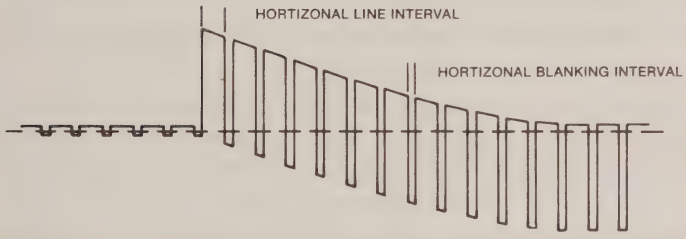


Figure 29



VIDEO SIGNAL CONTAINING A BLACK-TO-WHITE TRANSITION BEFORE CLAMPING

Figure 30(a)

VIDEO SIGNAL CONTAINING A BLACK-TO-WHITE TRANSITION AFTER CLAMPING

Figure 30(b)

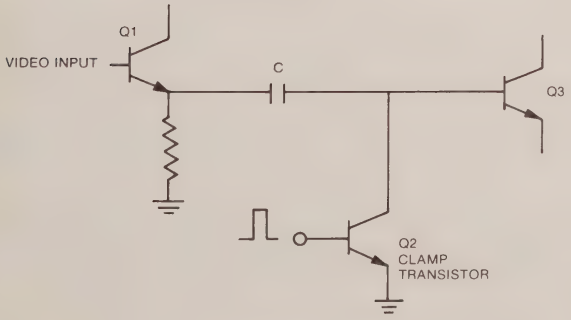


Figure 31

dance so that there is no discharge path for C. During the picture interval the input of Q3 must follow the signal variations, but the reference is from ground. Figure 30 (b) illustrates this action. Q3 is usually an FET or beta multiplier type circuit, but it can be a stage as an emitter follower if a very high beta transistor is used.

Back porch clamping is a superior way to clamp a TV signal and a complete discussion of this type of clamp is given in the section under special circuits.

The Synchronizing Signal

Understanding of the composite (horizontal and vertical) sync signal can be easily accomplished by taking the requirements of the signal in a step by step way.

We know that we need sync pulses occurring at 15,750 Hz for the horizontal synchronizing of the scanning lines, and we need pulses occurring at 60 Hz for the vertical sync. Figure 32 summarizes the evolution to the final composite sync signal.

The most important area of the sync signal is the so-called vertical interval. During the vertical interval both horizontal and vertical signals are present and the time relationship is complicated by the need to interlace the scanning lines of each of the two fields making up a 'frame' of television.

The pulse trains shown in figure 32 (a) represent the 1st and 2nd interlaced fields of a potential synchronizing signal. These trains of pulses represent the 15750 horizontal pulses along with the vertical pulse occurring at 60 Hz. The reason these pulse trains are

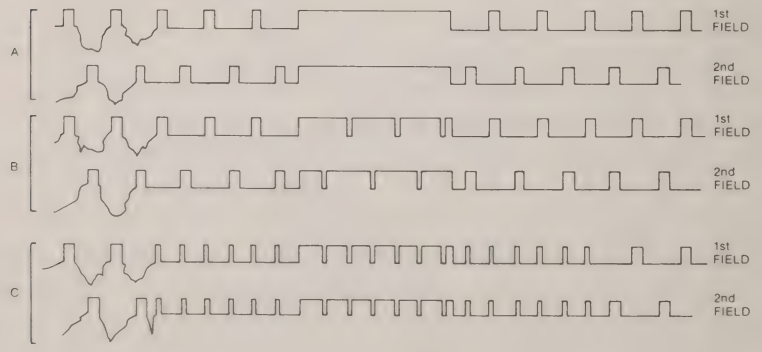


Figure 32

not satisfactory is that there are no horizontal pulses during the vertical sync time.

Since the receiver must remain locked all the time to preserve interlace some method of providing horizontal sync during vertical retrace is essential. The receiver must separate the vertical and horizontal pulses and this is relatively easy to do since the vertical pulse is about 40 times the width of the horizontal pulses.

To separate out the horizontal pulse information a differentiating network is used as shown in figure 33 (a). Only the leading and trailing edges are retained by this process. When the vertical pulse is present a period of 3H goes by before the next horizontal pulse is present with the pulse train of figure 32 (a). The absence of horizontal data during this 3H interval will allow the horizontal oscillator to fall out of sync in the receiver which will appear as a tearing action at the top of the picture. To avoid this the vertical sync pulse could be serrated as shown in figure 32 (b). We have now provided a leading edge which can be differentiated occurring at horizontal rate during the vertical sync pulse time. The problem with this solution is that the relationship of the pulses during the 1st and 2nd fields is not the same due to the frequency relationship of the horizontal and vertical frequencies (interlaced scanning). In this case the vertical oscillator will tend to sync sooner on the 2nd field and will result in a loss of interlace. The reason is that the vertical pulse is detected by integrating the pulses. An integrator sums the pulse width as shown in figure 33 (b). The area under the vertical pulse is many times larger than the horizontal pulses and the output of the integrator is much larger during the vertical pulse. In order to achieve interlace it is essential that the pulse train during the vertical interval be identical for both fields. This can be accomplished by combining the two pulse trains shown in figure 32 (b) as shown in figure 32 (c).

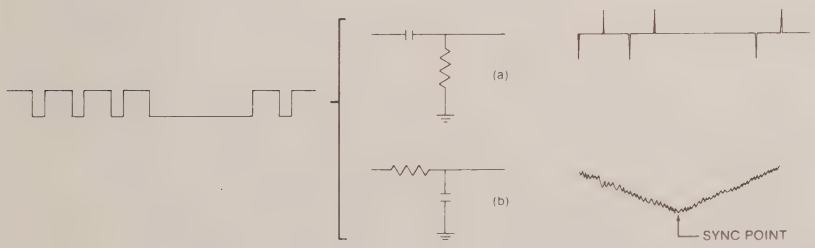


Figure 33

Visualize the two pulse trains of figure 32 (b) being slid together to produce the pulse train of figure 32 (c). The reason that the pulses preceding the serrated vertical pulse in figure (c) are more narrow is due to the integration process. The total 'area' or energy of the pulses preceding the vertical sync pulse must be identical for both fields so that the integrator will reach its peak output in exactly the same point for both fields. By reducing the horizontal pulse width by half and doubling the number we can achieve this need. These are called the equalizing pulses for obvious reasons.

With this configuration of the pulse train we have provided a leading edge at horizontal rate throughout the vertical interval and made the two fields identical during the vertical interval. The fact that we have introduced an extra leading edge (due to the extra pulses in the equalizing pulse section) is not critical since the flywheel action of the receiver free running oscillator ignores these pulses. The equalizing pulses following the vertical serrated pulse are not used and were included in the original specification to simplify design for the state of the art existing at that time.

Notice that the frequency of the equalizing pulses is at 31,500 Hz, or double the horizontal rate. Most sync generators use this frequency as the starting frequency and proceed to divide by 2 to obtain 15,750 Hz, then further divide to 60 Hz.

The total vertical interval is 33,000 μsec long which is the time required for vertical blanking. During this time some 30 horizontal sync pulse occur which means that some 30 lines of scanning are lost to the vertical interval. Therefore the active picture area of a TV picture is about 495 lines since there are a total of 525 lines in the TV frame.

SPECIAL CIRCUITS AND PRINCIPLES

Special Circuits and Principles

Clamping Circuits

The principles and necessity for clamping TV video has been described earlier in this book. The simple clamp circuits such as the diode clamp or transistor clamp will only clamp to the most negative portion of the signal. Sometimes, particularly in professional TV equipment, it is necessary to clamp at the black reference of the video signal which is the so-called back porch portion of the video signal.

Generally speaking a full wave clamp is used to do this. Figure 34 (a) is a simplified schematic of a full wave clamp circuit. The driving amplifier is a low impedance device coupled through the capacitor C to the following amplifier, which is a very high impedance input device. When the switches shown in figure 34 are open the input to Q2 has no return to ground and any signal impressed on the left of capacitor C will cause electrons to move in and out of the right side of capacitor C in concert with the signal variations. If capacitor C is charged to a specific value by closing the switches, then the variations caused by the signal on C will be referenced to this value.

The clamp circuit is really a bridge circuit as shown in figure 34 (b). Point A on the diagram will reach an equilibrium with point B when the bridge balances. So whatever voltage exists at point B will be the same at point A when the switches are open and this voltage will be the operating point from which the signal will vary.

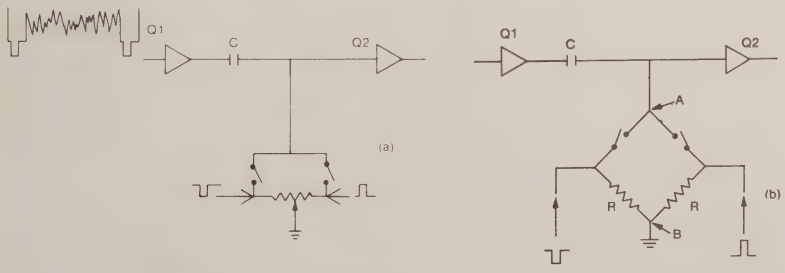


Figure 34

If the switches are caused to close during the back porch time then this voltage will become the black reference and the video portion of the signal will go up from this value and the sync portion will go down from this value.

Figure 35 illustrates an actual clamp circuit. The switches are two diodes which are driven into conduction during the backporch time as shown in the timing relation diagram of figure 35.

The essential points to keep in mind with this kind of clamp are; (figure 35)

1. Q1 must have low driving impedance.
2. Q2 must have very high input impedance.
3. The time constant of R1C2 and R2C3 must be long enough, and the voltage developed at each diode high enough that the diodes will not conduct as a result of the signal level on the other side of the diode, throughout the picture interval.
4. Clamp pulses P1 & P2 must have sufficient amplitude to cause the condition of voltage described above. These pulses are usually 5X amplitude of the video signal at the input of Q2.
5. C1 should be a small value to assure rapid charging to peak value in 1-3 μsec or so which is the typical pulse width of the clamping pulses P1 & P2.
6. When C2 & C3 charge up and the pulses are gone the time constant of R1C2 and R2C3 will keep the diodes reversed biased during picture interval of the video. Because of the bridge arrangement the circuit is balanced and no pulse leak thru to the video is experienced.

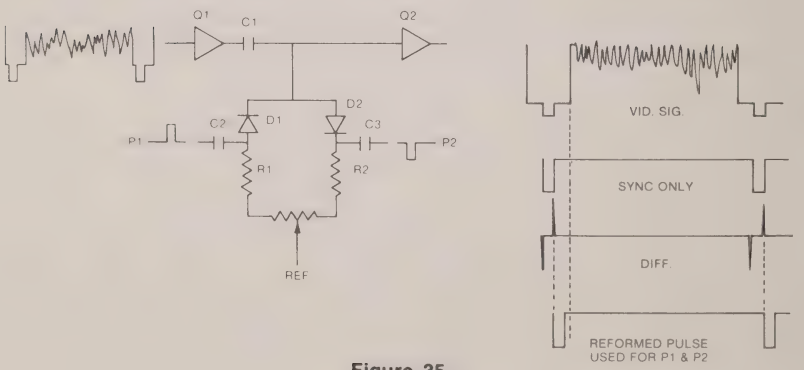


Figure 35

Delay Line Aperture Correction

The purpose of a delay line aperture corrector is to provide sharpening of picture transitions without introduction of phase shift errors which can degrade the quality of the picture.

Figure 36 illustrates a typical delay line aperture corrector circuit.

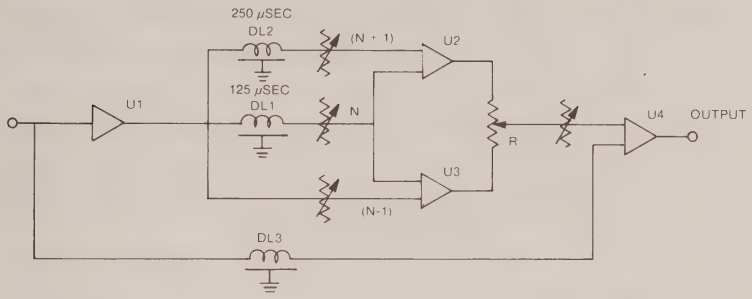


Figure 36

This kind of circuit can improve the transitions on a picture element by element basis. If we assume that we wish to correct elements as small as 125 nanosec which is the equivalent to 4 MHz, our basic delay line will be a 125 nsec line. (Two adjacent picture elements, say a black followed by a white, as in figure 37 = one cycle.) Three separate signals are developed by the circuit in figure 36, differing in time by 125 nsec, or the width of one picture element.

The output of U1 is split into three paths through DL1, which delays the signal by one picture element, through DL2, which delays the signal by two picture elements, and a straight through path which is not delayed. The 125 nsec delayed signal becomes the new reference element and this signal is labeled N in the figures. This N signal feeds both difference amplifiers U2 & U3. The other input signal to U2 is delayed N + 1 relative to our N signal while the second input to U3 is delayed N - 1 relative to our N signal. The (N), (N +1), and (N - 1) video signals are algebraically added in the differential amplifiers and the outputs of U2 & U3 are summed in potentiometer R to pro-

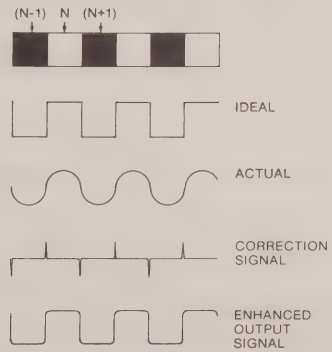


Figure 37

duce the aperture correction signal. A balance of equal excursions of the aperture signal can be obtained by picking off the arm of potentiometer R and this signal is fed to U4 where it is combined with the original video signal which is also present at U4. DL3 used in the video line to U4 is required so that the propagation delay of the correction signal is matched to the video signal.

The correction signal actually consists of 'spikes' which exist only when there is a black to white or white to black transition occurring in the video signal. The amplitude of these spikes will be a function of the degree of white to black or black to white change. In essence the circuit compares each picture element with the one preceding and the one following it on a continuous real time basis. Since the correction signal enhances the edges of transitions this circuit is sometimes called a signal enhancer.

Camera Optics Basics

The camera lens is used primarily to focus the scene image on the photosensitive surface of the pick-up tube. The two basic characteristics of lenses are focal length and f #.

The focal length (F.L.) of a lens is the distance from the optical center of the lens to the point behind the lens where the image comes into focus. E.G., if an object at infinity comes into focus 1" behind a lens the F.L. is 1".

F.L. governs the magnification of the image and therefore the field of view of the lens. Long focal length lenses bring objects up closer and the field of view is less. The field of view of a lens used with a camera is related to the scanned area by the following ratio: F.L./width of scanned area = Distance to subject in feet/width of field. Therefore the width of the field of coverage can be determined for a given F.L. lens and a camera using a Vidicon tube. The image size of the scanned area of a Vidicon is .375" High X .50" Width, (3-4 aspect ratio). If a 1" lens is used with the Vidicon the width of the field of view would be W = .5 X Distance to subject divided by 1. The height of the field of view would be ¾ X width.

If the subject were 5' away from the camera the field of view would be 2.5'. (The height would be 1.875'.)

The same formula can be used to determine the position of a given sized object to fill the screen . . . as a call card. If the card were 1' wide (it should be 9" tall) it would be placed at 1 = .5XD/1, or D = 2' away.

Suppose one wanted to determine the focal length of the lens required for a specific condition . . . say the scene to be televised is 20′ wide, but the camera cannot be placed more than 20′ away from the scene due to room size . . . well, F.L. = .5 X D divided by scene width = .5 X 20/20 or .5″ = F.L. which is a ½″ focal length lens. If the focal length of a lens is specified in millimeters which is the usual case, the relationship is mm/25.4 = inches. A 25mm lens is about a 1″ lens.

Figure 38 is a useful chart for determining lens F.L. and scene dimensions.

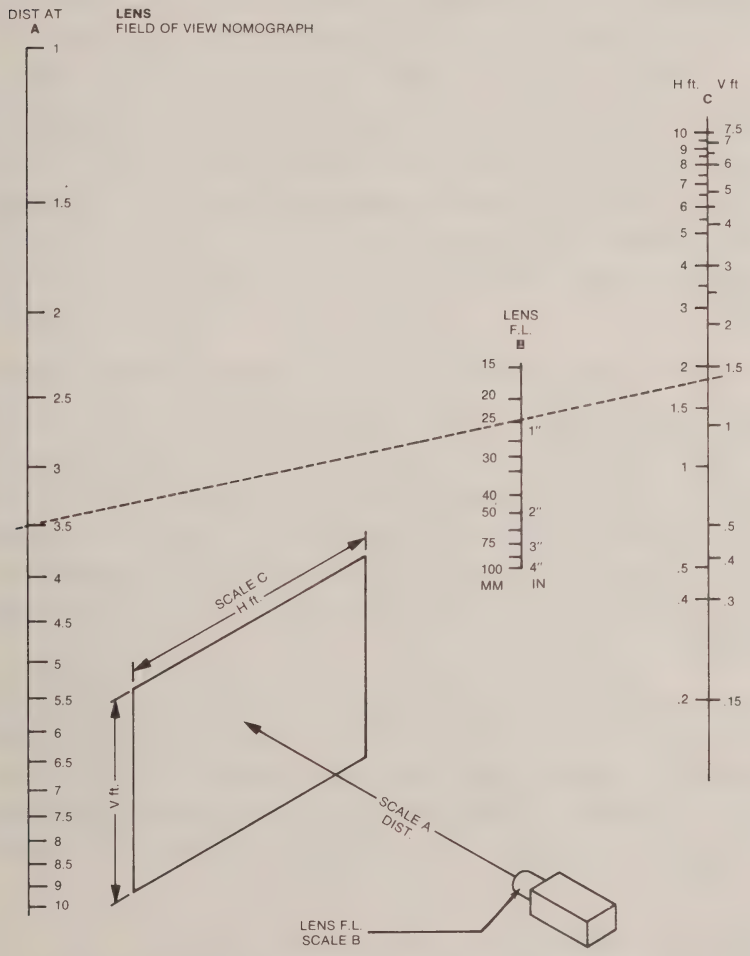


Figure 38

As we stated above, the f # of the lens is also important. The lens iris diaphragm operates like the human eye diaphragm, or iris. If one suddenly looks into a bright light the iris of the eye closes down to admit less light. Since camera tubes operate over a limited light level range the camera lens iris is used to control the amount of light striking the photosensitive surface.

The f # of the lens is a function of the F.L. and lens diameter with the iris wide open, or, f # = F.L./D, where D is the lens diameter. If a lens has a F.L. of 1" and the iris opening is .66", then the f # is 1.5. Lenses are referred to as 'fast lenses' or 'slow lenses' which are expressions describing the effect of the value of the f # on the performance of the lens. As the f # of a lens increases in numeric value the iris diameter decreases in opening size and less light volume is passed through the lens. In other words the amount of light passing through the lens is inversely proportional to the square of the f #'s. For example, to compare the amount of light through a lens with a speed of f 1.5 with a lens with a speed of f 3.0 one would use the following ratio:

$$\left(\frac{f1.5}{f3.0}\right)^2 = .25$$

the f 3.0 lens passes 1/4 the amount of light as the f 1.5 lens. Or to say it another way, if one has an f 1.5 lens and stops it down to f 3.0, the light passing through the lens is reduced 4X.

Another parameter of a lens is the depth of field. Depth of field relates to how much of the scene, from front to rear, is in focus. The shorter the focal length the lens has the more depth of field it has. Also the greater the distance to the scene the greater the depth of field. And, the larger the f # the lens has (or is used at) the greater is the depth of field.

Other characteristics of lenses, as chromatic aberrations, spherical aberration, vignetting, etc., are beyond the scope of this book but are not quantities of much concern for the average lens use for TV cameras unless the lens is of very poor quality. In other words, most lenses of reasonable cost are pretty good in regard to these specs. Very cheap lenses can affect performance of cameras and should not be used.

Resolution Limits of TV

Since the video bandwidth is limited to 4.2 MHz the size of the smallest picture element which will produce the equivalent fre-

quency can be calculated. For monochrome television one horizontal scanning action takes 63.5 μsec. This is derived from the fact that the scanning rate is 15,750 Hz. The period for one cycle is 1/15750 = 63.5 μsec. The retrace time (the time provided for the electron beam to go from the right side of the screen back to the left side) is 10 μsec., so the active scanning time is 53.5 μsec. In other words the scanning action involves 53.5 μsec from the beam to traverse left to right and 10 μsec to return to the left side to begin the next scanning line. To make the illustration clear we assume that picture elements are all black or white as shown in figure 3. To reproduce an equivalent frequency of 4.2 MHz the scanning beam spot must pass through successive black and white picture elements in .238 μsec (for a full cycle) (T (Period) = 1/f (frequency) ($.238 \times 10^{-6} = 1/4.2 \times 10^{6}$).

The limitation on the number of picture elements can be more easily understood by example. If we assume a picture of 8" x 6", which is an aspect ratio of 4X3 (the example is proportionally true for any size picture) the beam must travel 8" in 53.5 μsec. To produce a 4.2 MHz equivalent frequency the size of successive black and white elements would be equal to:

$$\frac{(.238 \times 10^{-6})\ (8")}{53.5 \times 10^{-6}}$$

which equals .0357 inches for a full cycle (i.e. beam passing through both B&W elements) or .0178 inches for one element. Therefore each black or white element is .0178" long (or about $\frac{1}{64}$" on 8" picture since $\frac{1}{64}$" is .0156") and to determine the number of total elements we can compare the area of one element with the total area of the picture. Each element is .0178" X .0134" (remember aspect ratio is 4X3) and picture area is 8" X 6". Dividing the picture area by the element area gives:

$$\frac{8 \times 6}{.0178 \times .0134} = 201{,}205+ \text{ elements contained in the area}$$

Since about 30 lines of scanning are lost to the vertical interval the actual picture area contains about 190,000 elements.

Modulation

In the US system of television amplitude modulation of the video carrier and FM modulation of the aural carrier is the standard. The

color subcarrier is both phase and amplitude modulated and this is sometimes called quadrature modulation.

There are three basic techniques used in amplitude modulation of the TV signal.

High level modulation, low level modulation, and IF modulation. In high level modulation the final RF amplifier collector is modulated by the video signal. High level modulation produces good efficiency and the final is operated Class C. The modulator must be able to handle the power required to current modulate the final.

Low level modulation requires less modulator capability since a low level power stage is modulated by the video signal. The low level modulated stage operates at the final RF frequency and the power level is raised to the desired amount by following Class A or AB RF amplifiers.

In IF modulation an intermediate frequency is modulated at very low level but this frequency cannot be multiplied up to the operating frequency since the modulation components would be multiplied as well . . . so the signal is heterodyned up to the operating frequency by using a mixer, and then Class A amplifiers used to arrive at the final power level desired.

For the aural signal conventional FM modulation is used but the deviation is limited to $\pm$ 25 KHz instead of $\pm$ 75 KHz as in radio FM.

(Still another method of modulation can be mentioned which is FM modulation of the video carrier. This type of modulation is authorized in the US for Microwave transmission and in France for their SECAM system. In FM modulation of the video a given frequency represents sync tip, black level and peak white level. The discriminator in the receiver is usually about 20 MHz wide to accommodate the modulation index swing of the modulation.)

Propagation

Propagation of radio waves at the 450 MHz region is more line-of-sight than at lower frequencies. In addition the character of the terrain affects propagation at high frequencies.

Naturally antenna heights and power output affect the distance that good signal strength can be received. Chart A relates frequency of operation and received signal strength. High elevation for the transmitter antenna and receiving antenna is more important than power output since the distance to the horizon is improved with antenna height, and doubling the power output only gives a 3 db improvement in received signal strength.

Since the antennas for television must be broadband antennas care must be exercised in selecting the antenna. There are a number of excellent broadband designs which can be used including multi-element colinears, corner reflectors, and other designs. Antenna gain comes from the directivity characteristics embodied in the antenna design. Omnidirectional antennas can also be made with gain by stacking depending upon polarization used, without the antenna becoming too large. Both vertical and horizontal polarization is used for ATV use. Each method has its advantages. For a repeater installation the advantage of vertical polarization is obvious. The mounting problems are reduced and antennas are available with nominal gains as well. The omnidirectional pattern is inherent. Horizontally polarized omnidirectional antennas are more complex and generally more costly.

For the individual, where gain is helpful and directional designs desired, the horizontal polarized antenna is probably cheaper and easier to design or buy. This antenna could be mounted in the vertical plane as well with proper mounts. This is also true of a colinear which is available commercially. The antenna should have a bandwidth of at least 6 MHz and have a flat impedance characteristic over the bandwidth.

Coax line has substantially more loss at higher frequency. Naturally it is better to use low loss copper line which may have a loss of less than 1 db at 500 MHz per 100 feet of line, but such line is very expensive if the transmission line is very long. However, only the best low loss foam line as RG/8 series should be used since losses of 3 to 6 db per 100 feet are very common. A 3 db power loss in the line cuts the antenna input power by half. Another source of loss is the coax connection which should be type N connectors and be carefully attached to the coax as well. Poor workmanship can create 2 to 5 db of losses at these frequencies.

In summary, to obtain the best transmission and receiving conditions one should select the antenna carefully, use high quality coax interconnection, type N connectors, and locate the antennas as high as possible above average terrain.

Transmitter Power

As is well known, symmetrical waveforms, as a sine wave for example, have an 'average' which falls midway splitting the two halves.

As shown in figure 39 this is not the case for an asymmetrical wave as shown in (b).

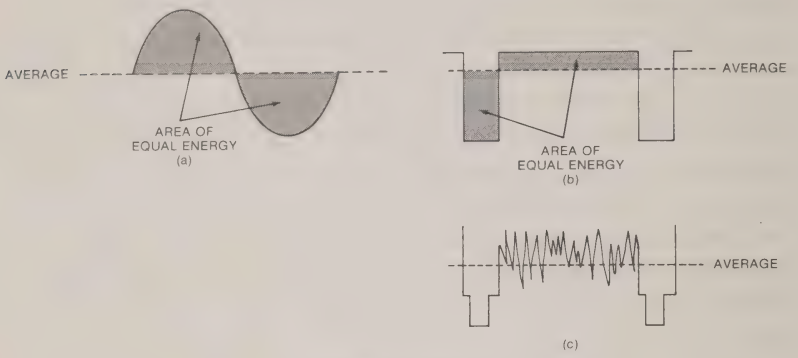


Figure 39

The average, or the line which splits the waveform into areas of equal energy, is off center for the pulse type asymmetrical waveform. A television signal is similar to the pulse type signal shown in figure 39 (c) and the determination of peak power is governed by the percentage of the duty cycle of the asymmetrical waveform.

Peak power of a television transmitter is determined by operating with a black picture, i.e. sync only modulation, and reading average power directly from a wattmeter while terminated in a non-reactive load which is equal to the output impedance of the transmitter. (See figure 40.)

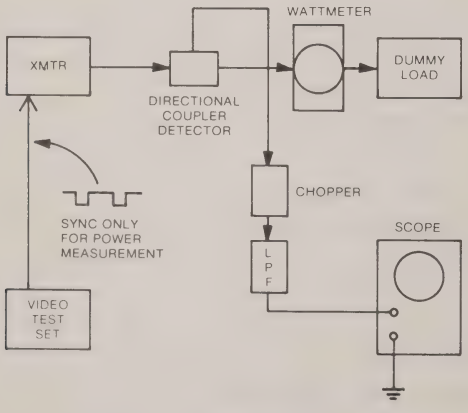


Figure 40

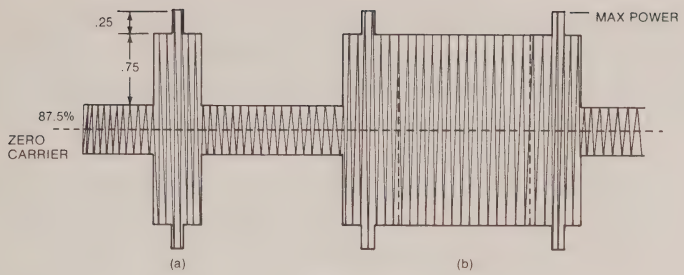


Figure 41

In the case of a television signal, the duration of all the vertical, horizontal, and equalizing sync pulses adds up to 8.9% of the TV frame time. The relative amplitude of the sync and blanking portions of the modulating signal is .25 and .75 respectively as shown in figure 41. Note that the measurement of peak power requires the use of a sync only modulating signal, as illustrated in the figure 40.

The calculation for determining peak power is:

$$\frac{\text{Ave Power}}{\text{Peak Power}} \quad \frac{[.75 + (.25 \times .089)]^2}{1} = .596$$

To determine peak power the wattmeter reading must be multiplied by 1/.596 = 1.68. (If no modulation is present the peak power is the average multiplied by 1.78.) Remember that this measurement is based upon use of proper sync pulse amplitude as the modulating signal.

When ordinary video signals modulate the transmitter the average power will vary as a function of the APL of the signal, but if the modulator is clamped to black level or tip of sync, the peak transmitted power will always be a maximum at sync tip. It is also important that such reference clamping be utilized to avoid variations in background level of the picture as a function of video content.

Another reference which should be recognized is peak white reference which is set at a maximum of 87.5% This is done to avoid overmodulation resulting from transient white peaks from specular reflections or other highlights in the televised scene. Figure 42 illustrates the condition where overmodulation occurs producing

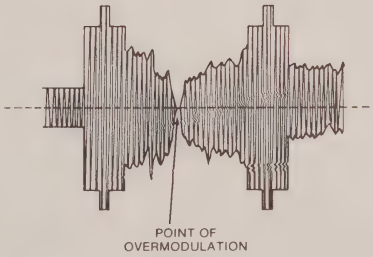


Figure 42

zero carrier power for the interval of such overmodulation. Effectively the carrier is interrupted for the period of overmodulation peaks producing an unpleasant 'sync buzz' sound in the detected picture at the receiver because the picture is repeatedly transmitted at the rate of 30 frames per second.

The measurement of modulation percentage is accomplished by establishing a reference zero using a chopper to interrupt the detected video. Figure 40 illustrates a typical test set-up for measuring power and percentage modulation for television transmitters.

Figure 43 is a convenient graph to convert average power as measured on a wattmeter to peak sync tip power.

Using a test set-up similar to figure 40 one can measure all pertinent parameters of the transmitter. Addition of a spectrum analyzer will provide measurement of transmitter spurious emissions as well.

The directional coupler in the transmission line includes a detector diode whose output is filtered to remove the RF component and is the video signal as it appears after modulation on the RF carrier. The video should be passed through a low pass filter to remove modulation components beyond 4-5 MHz.

A video test set producing window signals, stairstep and linearity signals, etc., should be used for transmitter measurements since signals produced from a camera viewing test charts may introduce aberrations which are present in the camera video as noise, nonlinearity, etc. It is also difficult to make multiburst or frequency response checks using a camera signal.

A step by step testing procedure is included in the discussion of the ATV transmitter which follows later.

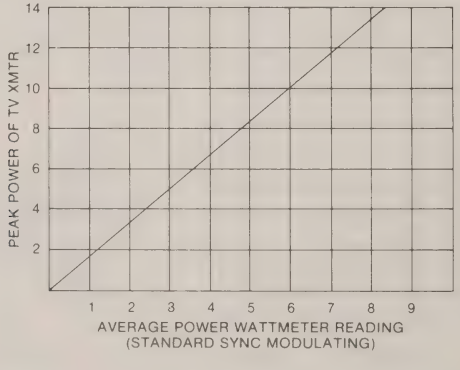


Figure 43

SUMMARY OF BASIC PRINCIPLES OF COLOR TV

Basic Principles of Color Television

Monochrome television requires that brightness and synchronizing information be transmitted; for color transmission it is necessary to add information relating to Hue (what color is it) and Chroma (how saturated is the color).

Color television requires the addition of a subcarrier which is both phase and amplitude modulated. The color subcarrier frequency is 3.579545 MHz. The amplitude of this subcarrier represents the chroma or saturation of the color. The phase angle of the subcarrier represents the hue.

Before going into detail on the color information, there are some points that should be discussed regarding color vision in general.

Many tests have been performed to confirm information regarding human vision in color. From these tests it has been determined that the primary thing we perceive is brightness, both in greys and in color. The eye also makes a distinction between hue (red, green, blue, etc.) and saturation, or purity of color; i.e., deep red and light red, etc. Figure 44 is the so-called chromaticity diagram. This diagram allows one to understand the relationship of colors, saturation, etc.

The colors occupy different segments of this diagram. The outer edge of the curved triangle (called the Spectrum Locus) represents the maximum purity or saturation of the color. This point is sometimes confusing and I will try to explain it this way. You will note the point in the approximate center of the diagram labeled CIE standard source. This point has been established as reference white. As you move out from this point (which represents white) along any line you want to draw—the color represented along that line becomes less and less diluted by white. For example, if we pick the line A-C, which is the orange-cyan axis, to the right of the standard white, the color is white mixed with a little orange (pastel pinkish), a little further out orange is diluted by less white (pink orange) and little

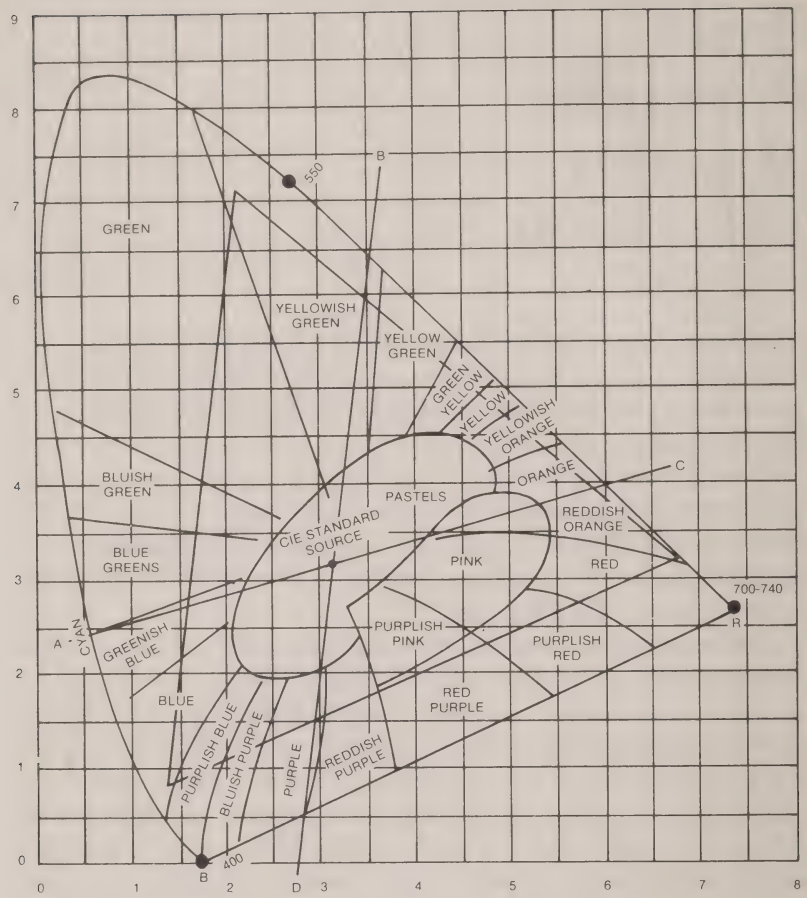


Figure 44

further out it is diluted by even less white (orange pink), and the furthest out it becomes pure orange or, as we say, fully saturated, or has maximum purity.

This is applicable whichever line or axis you wish to pick through the CIE white. The horseshoe represents all the color and saturation we can see. The triangle within the horseshoe represents all the colors and saturation our TV system can reproduce.

To understand the theory behind our color system better we must explain some facts about color mixtures using light as the source (rather than pigments).

If we had three spotlights each having a different filter—one red, one green, one blue, of the right hue—and if we were able to vary the

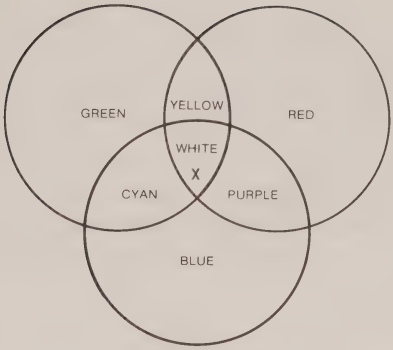


Figure 45

intensities independently—and we focused them on a wall so that they overlapped as shown in figure 45 the point labeled X would be white. This is true if the intensities and hues were adjusted just right. The intensity is analogous to amplitude if we were talking about electrical signals. For our color signals, taking into account the phosphor efficiencies and other non-linearities such as the approximate square-law transfer characteristics of picture tubes, the amplitude ratios for the three primaries is $E_Y = .59_G + .30_R + .11_B$. This mixture produces a composite amplitude variation known as the luminance (Y) signal. In a black and white set this is the monochrome signal producing regular black and white picture. In a color set it is the luminance signal carrying the detail of the picture.

Color is transmitted by sending the luminance signal and two other signals containing only information related to hue and saturation (on the chroma subcarrier).

To illustrate how the luminance and chrominance signals are combined into a 4 MHz band, here is a review of the requirements. Most professional TV color cameras use three tubes, one for red, green, & blue.

Since each of the thee camera chrominance tubes produces signals extending beyond 4 MHz, you might expect a bandwidth need for 12 MHz to accommodate the signal. Actually, two things are done to eliminate this problem. First, the color difference signals are band-limited to 1.5 MHz for the E_I and .5 MHz for the E_0 signal. Second, the color signal is frequency interleaved with the luminance signal.

To explain the first point it is necessary to explain the I and Q signals and to go back and discuss some characteristics of human vision to explain band-limiting of the chrominance signals.

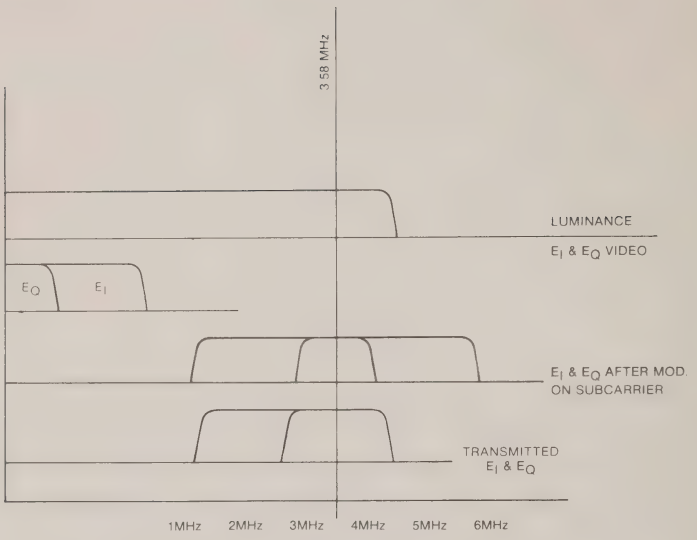


Figure 46

Tests show that the eye becomes progressively more color blind as the size of the viewed object becomes smaller. First, with large objects, the eye has three color vision, then as the object size is reduced, the eye has two color vision and, finally, for small objects, only brightness is perceived. This means that for the small elements in the televised scene (the high frequency components) the eye sees in gradation of greys, regardless of the color of the element, or to express this in another way, the eye sees final detail in the picture in black and white regardless of the color. The size of the object where the eye fails to recognize color varies with the color. Some colors become grey to the eye sooner than others for the same size object. To take care of the entire gamut of colors, it is only necessary to transmit some colors out to a bandwidth of 1.5 MHz and others only as far as .5 MHz, as shown in figure 46. Tests were made to determine the optimum axis on the chromaticity diagram for the wide-band color information and the narrow band color information. It was found that the eye is most sensitive along the orange-cyan axis and the least sensitive along the yellow-purple axis. The orange-cyan axis is called the I axis (represented by the line A-C on the chromaticity diagram) and the other axis (B-D) the Q axis. Also, to correlate this to bandpass, the transition from green to purple

would have steepness of rise corresponding to a bandpass of .5 MHz and the transition from cyan to purple would have steepness of rise equal to 1.5 MHz. The transition from green to red would contain components passed by both the .5 and 1.5 MHz channels. Also, the I and Q axis when translated to vectors comes out to be offset from the B-Y and R-Y signals by 33 degrees as shown in figure 51.

To represent the position of all three primaries, we can draw a diagram as in Figure 47.

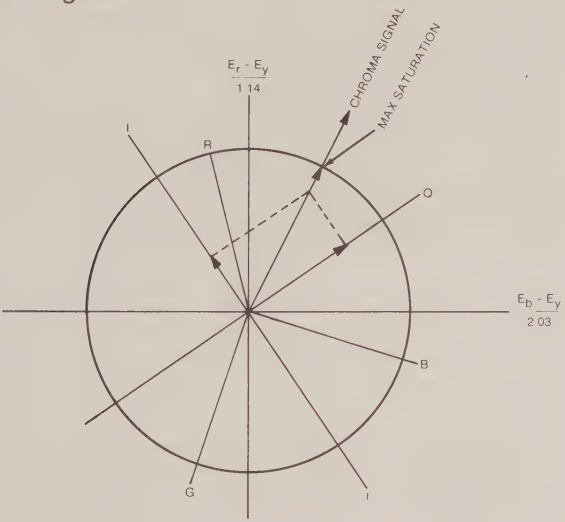


Figure 47

Detail in the televised scene producing frequencies above 1.5 MHz are reproduced in black and white, or as varying brightness only, detail producing frequencies from .5 MHz to 1.5 MHz are reproduced in two color orange-cyan fashion, and finally, detail producing frequencies less than .5 MHz are produced in three colors: red, green and blue.

Electrically, the I and Q signals are related to the rest of the system in a very simple way.

$$E_Q = .21E_r - .52E_g + .31E_b = .41\,(E_b - E_y) + .48\,(E_r - E_y)$$

$$E_I = .6E_r - .28E_g + .32E_b = .27\,(E_b - E_y) + .74\,(E_r - E_y)$$

These equations show how the camera signal (or the difference signals) must be added to produce the I and Q signals. Addition in a simple resistor matrix is all that is necessary. The negative sign is no problem since we need only to send the signal through a single

stage to invert it to generate the needed negative value. The E_r, E_g, E_b are those signals directly out of the camera tubes. (The $(E_r - E_y)$ and $(E_b - E_y)$ would be derived directly in the matrix following the camera outputs.) These values can be anything from zero to 1 volt, depending on the hue, saturation and brightness of the point under consideration. The coefficients define directly the matrix settings. The I and Q signals generated in the matrix go directly into the bandpass limiting filters, 1.5 MHz for the I and .5 MHz for the Q.

To fit the color signal in the same frequency space with the monochrome signal frequency interleaving is used.

It was discovered that the sideband energy in our TV system was centered around even multiples of the scanning frequencies (15750). This is a result of the scanning method itself, and very fortunate for the color transmission problem. There are gaps in the frequency spectrum between the even harmonics of scan frequency.

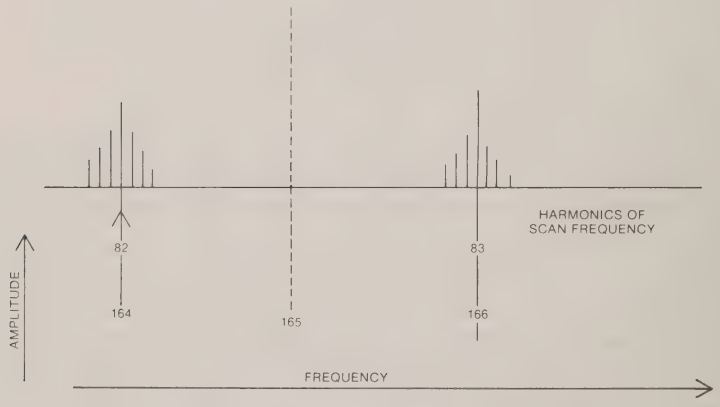


Figure 48

As shown in figure 48 for each harmonic of a particular frequency there are subsidiary components spaced from it by the vertical scan frequency. You will note that there are substantial gaps. It is convenient to speak of these gaps in their relation to one-half the horizontal scan frequency. When we do this the regions filled by the monochrome signal are the even harmonics of horizontal scan and the blank areas are related to the odd harmonics of the scan frequency. To show that if we put a signal in the blank areas it will produce no interference on a black and white set, we can draw the relationship as figure 49.

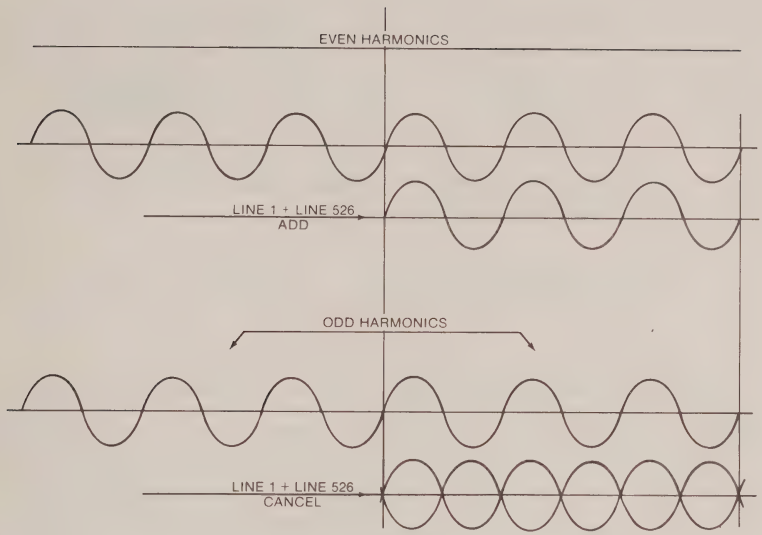


Figure 49

Since a complete frame of television picture consists of an odd number of lines, you can see that an odd number of line intervals has elapsed between the scanning of one particular line and that same line in the next frame 1/30 second later, so components having odd harmonics in the frame have one polarity, and will cancel; even harmonics will reinforce.

What this means is that in our present black and white system each frame will reinforce the last, giving a persistent picture while, and if we insert signals at odd harmonics (in between the used areas in our present black and white spectrum), it will tend to cancel out in black and white receivers.

It is obvious that if we were simply to generate our color signal by the same method we generate our black and white picture, we would still produce components in the region of the even harmonics of one-half scan frequency, just like our present black and white does. In order to make these occur at odd harmonics, we have to do something. By placing the information on a carrier which is chosen as an odd multiple of one-half line frequency, we get the necessary frequency interleave.

One of the basic principles governing the selection of the color subcarrier frequency was the requirement that the transmission of a color signal received on a monochrome TV set would cause little or no adverse viewing problems.

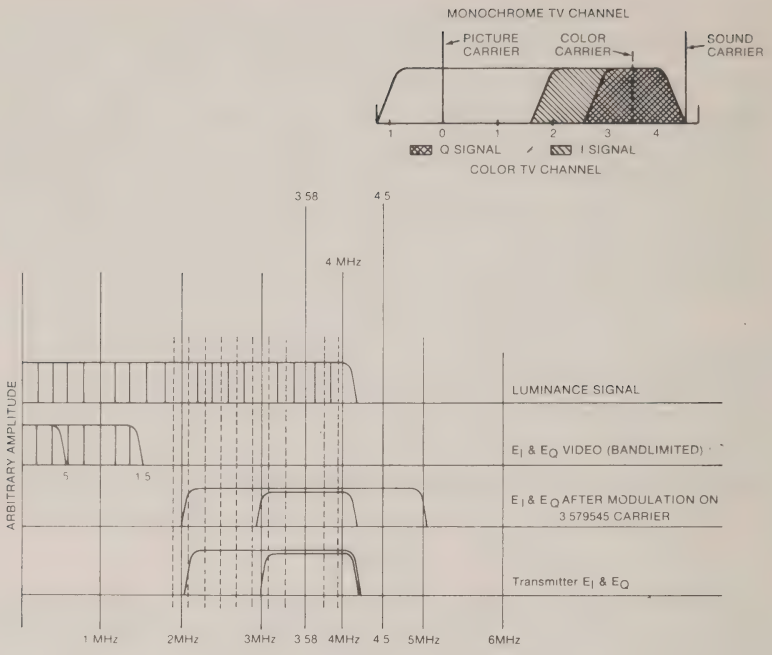


Figure 50

Since the upper end of the video passband is approximately 4 MHz putting the subcarrier at the high end would reduce the probability for objectional interference.

The frequency of the subcarrier was picked on the premise of frequency interleaving with the luminance signal AND the sound subcarrier at 4.5 MHz.

Figure 50 illustrates the relative position of the sideband energy between the modulated subcarrier and video carrier sidebands. In order to accomplish this frequency interleaving an odd multiple of halfline frequency must be used. The line frequency is 15,750 Hz and one-half of this is 7875 Hz. To achieve a high subcarrier frequency near the top end of the video passband a multiple of 455 was used. 7875 X 455 = 3.583125 MHz . . . but . . . this selection did not interleave with the sound carrier. By making the sound carrier/color subcarrier beat frequency an odd multiple of half line frequency the visability of the beat is greatly reduced. To achieve both goals it was necessary to modify the TV line frequency and frame frequency from the standard of 15750 and 30 Hz.

Therefore the NTSC and FCC established the new standards as follows:

$$F_L = \text{Horizontal line Frequency} = \frac{4.5 \times 10^6}{286} = 15734.26$$

$$F_F = \text{Field frequency} = \frac{F_L}{525} \times 2 = 59.94 \text{ Hz}$$

(frame frequency = 29.97 Hz)

$$F_S = \text{Subcarrier frequency} = \frac{455}{2} \times F_L = 3.579545 \text{ MHz}$$

The choice to modify the line and field rates was made instead of modifying the 4.5 MHz sound carrier frequency because it was felt that existing monochrome TV sets would not be affected by the .1% change for the scanning frequencies while a more serious problem could exist if the RF 4.5 MHz frequency was changed.

Figure 50 shows the relationship of the carriers in the 6 MHz band used for TV transmission. (Note that it is common to refer to the 3.579545 MHz subcarrier as the 3.58 MHz subcarrier to avoid writing out the long number.)

The main difference between black and white receivers and color receivers is the addition of the color decoding circuits and the high voltage supply.

The high voltage supply needs to be well regulated, otherwise beam current differences could produce brightness variations (due

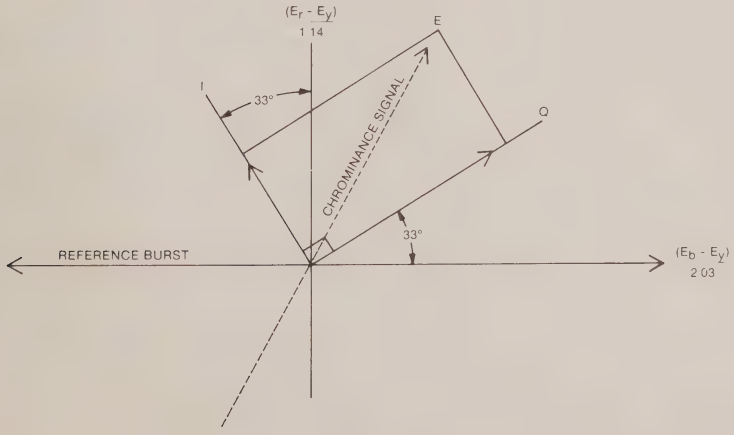


Figure 51

to H.V. loading) not present in the original scene and, depending on the color tube type used, various forms of correction are required to correct for flat faced tube geometry, etc.

The most complex part of the color set is the color sync circuit. The function of this color sync circuit is to produce a 3.579545 mc signal whose phase relationship to the burst is at all times within a few degrees. It must be relatively immune to noise and other error causing signals.

Summary

The difference between color transmission and black and white transmission is the addition of the chrominance carrier and the reference burst on the back porch. The phase of this carrier carries the hue information and the amplitude of this carrier the saturation of that hue. The chrominance carrier is modulated with an I signal 57° away from the reference burst and a Q signal 90° + 57° away from the reference burst. These two modulations (I and Q) are placed on the carrier effectively in quadrature thereby eliminating crosstalk between these modulations and allowing the I and Q to be recovered in the receiver independently. The I and Q signals add vectorily and determine the phase and instantaneous amplitude of the chrominance carrier and thereby the hue and saturation. The brightness, or intensity, of the color is filled in by the luminance signal as well as filling in the detail in mixed-highs fashion. The luminance signal acts as the monochrome signal on black and white sets. The color carrier and its modulated sidebands (if passed at all by the black and white IF circuits) will tend to cancel at the picture tube, due to the odd harmonic relationship of this information, giving cancellation between each frame.

To give the receiver a reference point, 8-11 cycles of reference carrier are sent along with the signal on the back porch of the blanking signal. The reference burst is used to lock the phase of the local 3.58 mc osc. at the receiver.

Table II is the NTSC color TV specification.

CONSTRUCTION PROJECTS

Construction Projects

A Television Transmitter for Operation in the 420-450 MHz Band

Television signals require broadband devices to pass video frequencies up to 4 MHz or so. The design described here is an all solid state design and is capable of passing excellent color TV video at a maximum sync tip power of 12-15 Watts.

Almost all of the construction utilizes PC card construction for each module of the transmitter. Figure 52 is a photograph of the transmitter showing the internal layout of the various modules. Figure 53 is a block diagram of the transmitter.

The RF chain consists of the exciter, tripler, and final RF power amplifier. The final is high level modulated by the video modulator to assure excellent linearity. Provisions are made to allow either audio subcarrier or video carrier audio modulation by front panel selection. This is desired because different areas of the country have adopted different modulation methods for the aural signal. In either case the audio signal is transmitted along with the video and does not require a separate transmitter for the sound transmission.

1. Aural Subcarrier Generator
2. Exciter
3. Varactor Tripler
4. Power Amplifier
5. Video Modulator
6. Antenna Relay

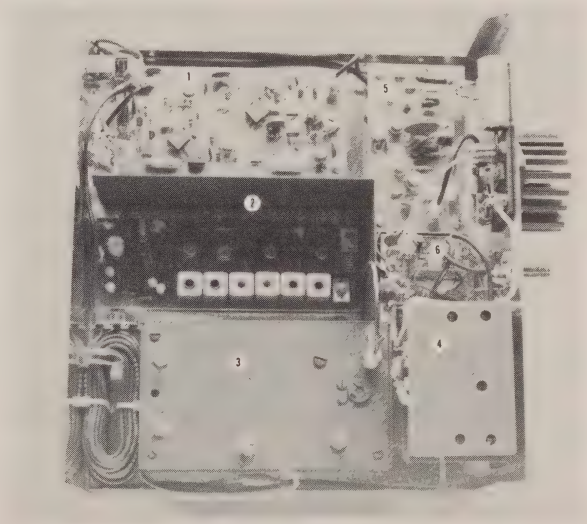


Figure 52

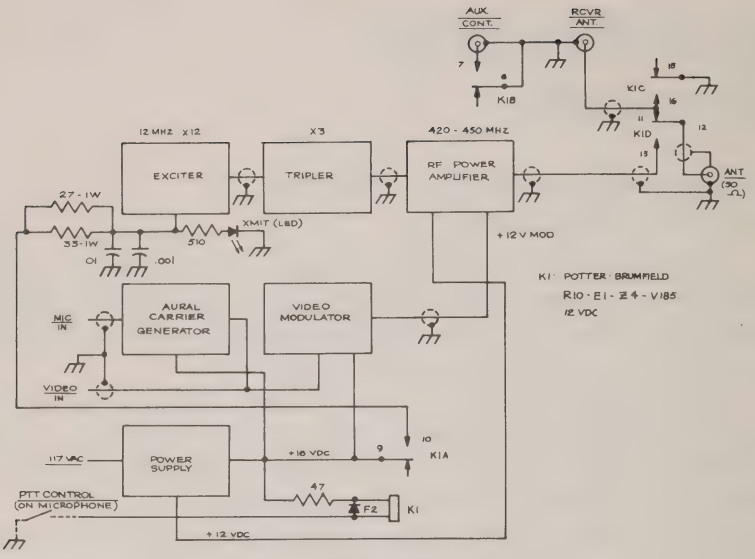


Figure 53

Construction Techniques

The Exciter

Figure 54 is the schematic of the exciter unit. The crystal frequency is selected in the 12 MHz range to assure easy availability and excellent stability. The xtal frequency is multiplied 12X in the exciter portion by tripling at the output of the oscillator, then doubling (Q2), then doubling again (Q3), which is tuned to the 12th harmonic of the fundamental. Q3 then drives Q4 which is a class C power amplifier.

The output of Q4 feeds a 50 ohm matching network consisting of L8, C24, and C25 which allows a small section of coax to be used to connect the exciter output to the Varactor tripler module.

The operation of the video carrier FM sound modulation circuits will be covered in the discussion of sound modulation found later.

Care should be exercised in laying out the PC card to provide a good ground plane and to shield or orient the coils to prevent mutual coupling. The coil data for L1 thru L6 is based upon using shielded cans around the coil form. All pertinent data is shown on the schematic.

The exciter is a PC card designed by VHF Engineering Co. A complete exciter as described here can be purchased from APTRON LABORATORIES or VHF Engineering Co.

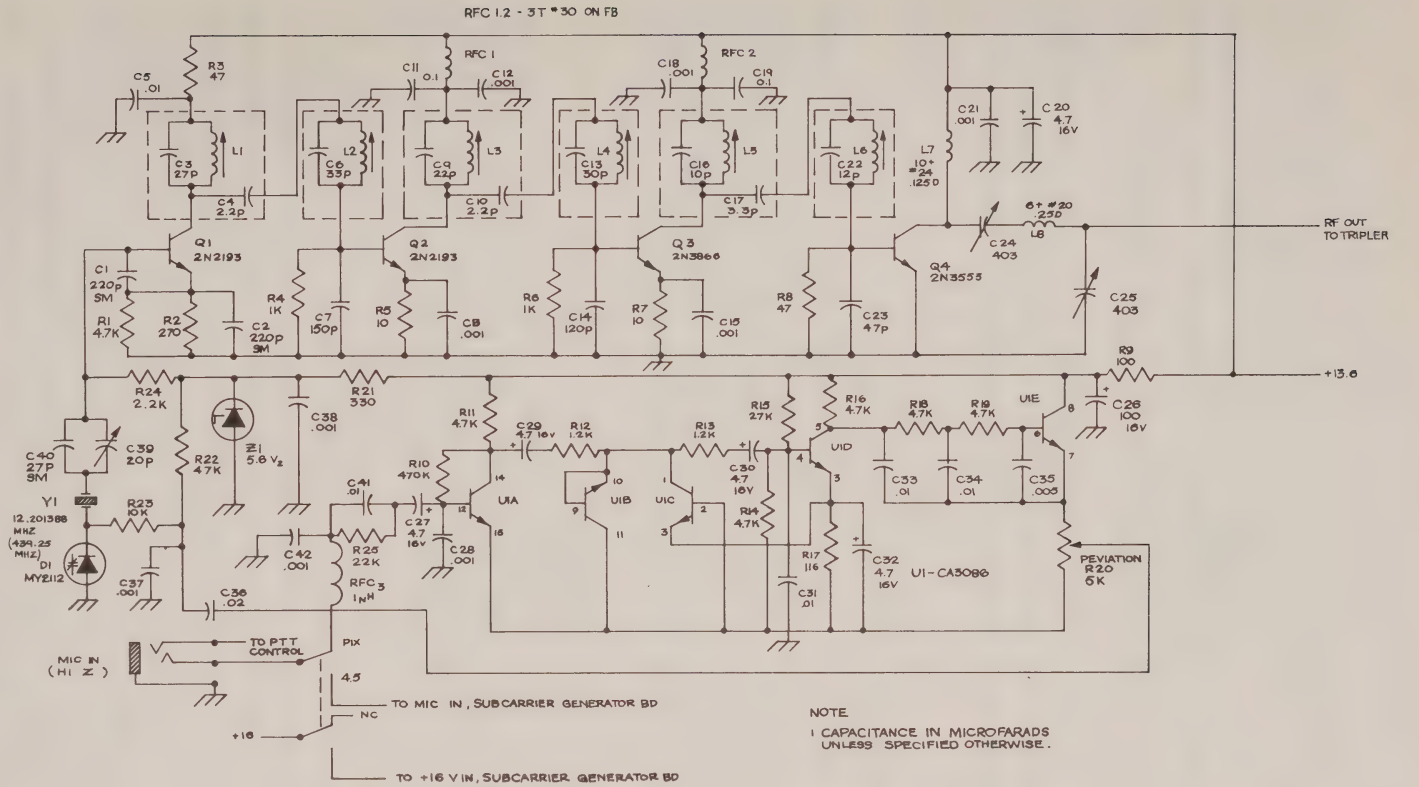

RFC 1,2 - 3T #30 ON FB
RFC 1
RFC 2
R3 47
C5 .01
C11 0.1
C12 .001
C18 .001
C19 0.1
C21 .001
C20 4.7 16V
L1
L2
L3
L4
L5
L6
L7 10+#24 .125D
C3 27p
C6 33p
C9 22p
C13 30p
C16 10p
C22 12p
C4 2.2p
C10 2.2p
C17 3.3p
6+#20 .250 L8
C24 40?
RF OUT TO TRIPLER
Q1 2N2193
Q2 2N2193
Q3 2N3866
Q4 2N3553
C1 220p SM
R1 4.7K
R2 270
C2 220p SM
R4 1K
C7 150p
R5 10
C8 .001
R6 1K
C14 120p
R7 10
C15 .001
R8 47
C23 47p
C25 40?
R9 100
+13.6
R24 2.2K
R21 330
C38 .001
C40 27P SM
C39 20p
R22 4.7K
Z1 5.6 Vz
R11 4.7K
C29 4.7 16V
R12 1.2K
R13 1.2K
C30 4.7 16V
R15 2.7K
R16 4.7K
R18 4.7K
R19 4.7K
U1E
C26 100 16V
U1D
C33 .01
C34 .01
C35 .003
Y1 12.201388 MHZ (439.25 MHZ)
D1 MV2112
R23 10K
C37 .001
C41 .01
R10 470K
C27 4.7 16V
U1A
U1B
U1C
R14 4.7K
C28 .001
C42 .001
R25 22K
RFC3 1MH
C36 .02
R17 116
C32 4.7 16V
U1-CA3080
C31 .01
PEVIATION R20 5K
MIC IN (HI Z)
TO PTT CONTROL
PIX
4.5
NC
+16
TO MIC IN, SUBCARRIER GENERATOR BD
TO +16 V IN, SUBCARRIER GENERATOR BD
NOTE
1 CAPACITANCE IN MICROFARADS UNLESS SPECIFIED OTHERWISE.

Figure 54

Since the xtal frequency is multiplied 36X to the final output frequency the xtal netting should be done precisely using a frequency counter. E. G. If the output frequency is 439.25 MHz (which is a typical frequency used) the xtal frequency is 12.2013 MHz. The exciter multiplies the xtal frequency 12X, so the output of the exciter will be 146.41656 MHz.

The exciter will produce about 1 watt to 1.25 watts of drive to the tripler module.

As stated previously, the use of solid grounds using binder head screws is important, and the pc board should be shielded from the other modules in a way similar to that shown in the photo of figure 52.

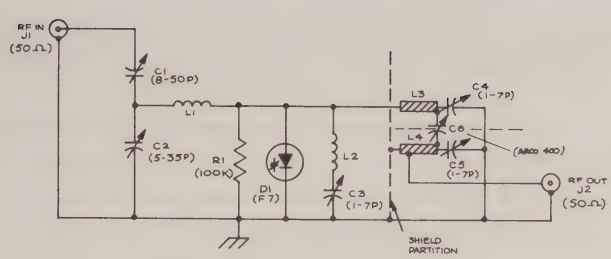
Testing Procedure

Connect the exciter output to a 2 watt power meter and terminate in 50 ohms. Connect a VTVM to the emitter of Q2 and tune L2, then L1, for max meter reading. Move VTVM to emitter of Q3, scale 3-5V, and adjust L4, then L3, for max reading. Now look at power meter and adjust L6, L5, C24, & C25 for maximum. You should go back through procedure to peak up all readings.

The Varactor Tripler

One of the principal factors to keep in mind when using multipliers is the fact that frequencies other than the desired frequency harmonics will be present at the output of the multiplier and be a source of TVI or improper frequency transmissions at the output of the transmitter.

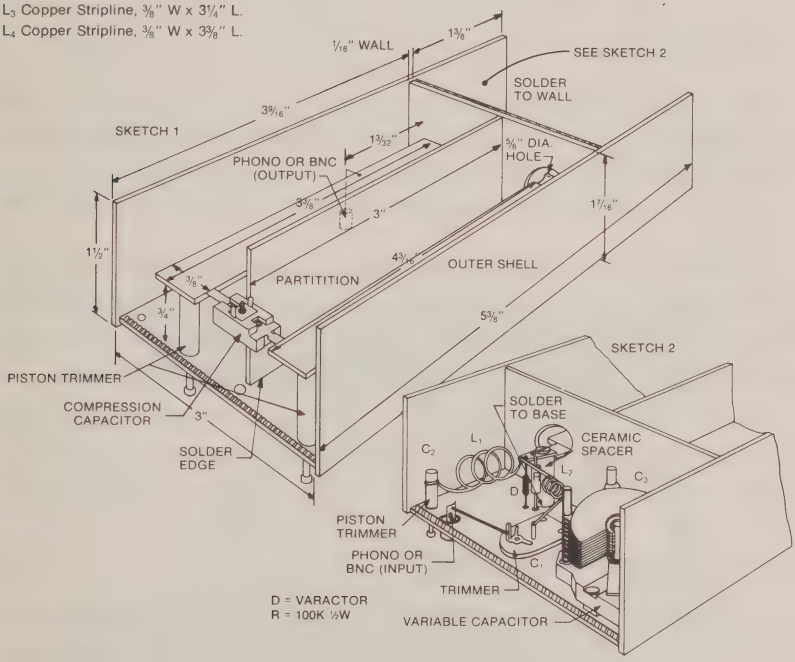
Varactor triplers have an advantage that while essentially passive devices except for the varactor (no DC power is supplied) substantial efficiencies are possible. The power is derived from the driving stage (in this case the exciter). Since varactor multipliers create high energy harmonics, many of which are unwanted, the use of an efficient filter at the output is essential. This design, shown in figure 55, uses a stripline filter at the output which is integral to the design which is housed in a completely shielded enclosure whose dimensions are important to the design. Figure 56 is a sketch of the tripler assy giving essential dimensions of the structure. The output of the tripler is at the final operating frequency and has a power level of approximately 400 mw.



COIL DETAIL

L_1 6t, #18, 3/16" ID, 1/2" L.
L_2 3½, #16, 3/8" ID, 1/2" L.
L_3 Copper Stripline, 3/8" W x 3¼" L.
L_4 Copper Stripline, 3/8" W x 3⅜" L.

Figure 55



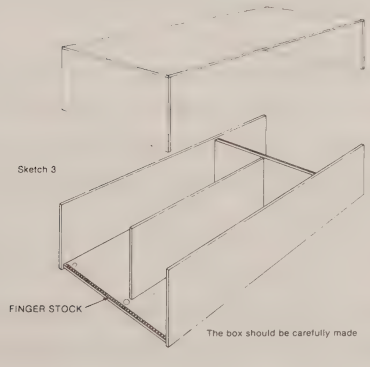


Figure 56

Referring to figure 55, the input to the tripler is parallel resonant to the input frequency (the exciter output), and is directly connected to the varactor diode which because it is heavily driven, generates harmonics of the input. The series tuned idler circuit, L2, C3, recirculates the 2nd harmonic of the input frequency through the varactor. The output circuit L3, C4, is tuned to the 3rd harmonic of the input. Following is the stripline filter L4, C5, which heavily attenuates all unwanted frequencies generated by the varactor. The output line is taped at 50 ohms feeding the final power amplifier.

Testing Procedure

Before applying RF to the system terminate the output in 50 ohms and using a vhf dip meter dip L1 for resonance at the exciter output frequency (12X the fundamental), by adjusting C2.

Now dip L2 for resonance using C3 at 2X the exciter output frequency.

The output of the tripler should now be fed to a power meter and terminated in 50 ohms. The output power level is only 300-400 mw so use a 1 W element. You can now apply RF power input from the exciter (remember the tripler requires no external DC power).

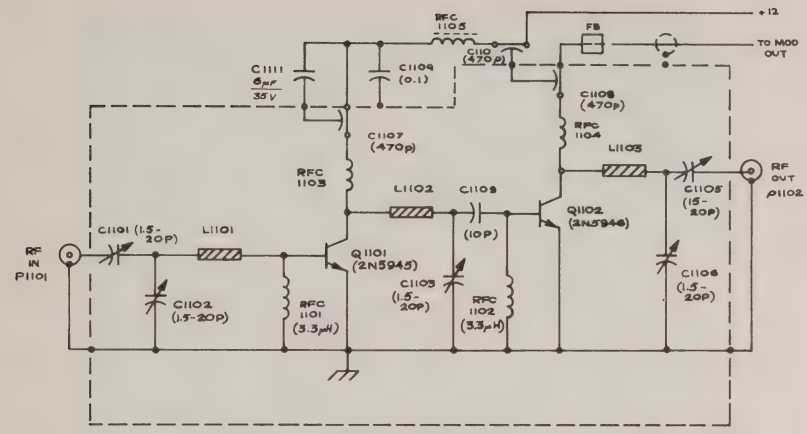
Refer to the output power meter and adjust C1, C2, C4, C5, & C6 for maximum output. Recheck C4 & C5 adjustment for maximum output peaking. The output power will be in 300-400 mw range.

The Power Amplifier

One of the difficulties in design of a television power amplifier is the need for modulation of fairly high frequencies in the video signal, which go to 4 MHz, and the need for good RF decoupling of the devices used in the power generating stages.

The power amplifier consists of two cascaded class C amplifiers in a stripline pc board configuration which is mounted in a completely shielded enclosure and in turn mounted to a heatsink. It is essential that the power transistors be thermally connected to the heatsink to efficiently dissipate heat generated in these devices.

Figure 57 is the schematic of the power amplifier. The inductances, L1101, 1102, 1103 are printed on the PC board. Again, it is essential that lead lengths of components be kept very short and that the electrical and mechanical equivalent parts be used in the construction of this unit. Figure 58 is a photo of the interior of the



L1101-L1103: Printed stripline. See PC board layout detail.

RFC 1105—Ferruxcube VK-200-20/4B

Figure 57

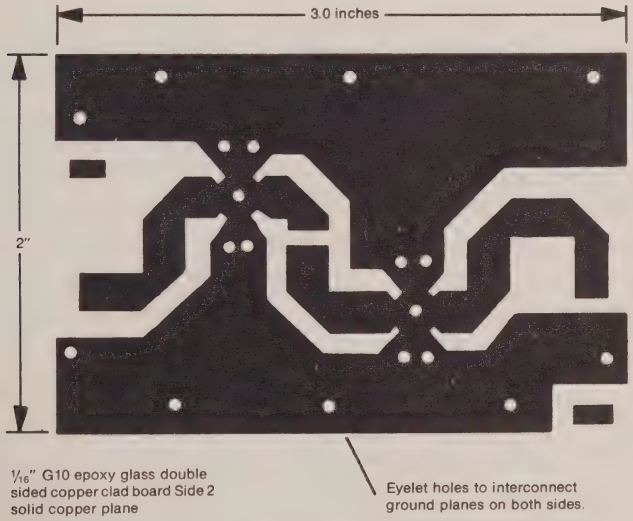

3.0 inches
2"
1/16" G10 epoxy glass double sided copper clad board Side 2 solid copper plane
Eyelet holes to interconnect ground planes on both sides.

Figure 57(a)

power amplifier with the cover removed and clearly shows the placement of parts. A full size PC artwork is shown in figure 57a.

Testing Procedure

Connect the tripler output to the power amp input thru a UHF directional coupler with SWR meter, and the power amp output to a power meter terminated in 50 ohms with 20 watt rating.

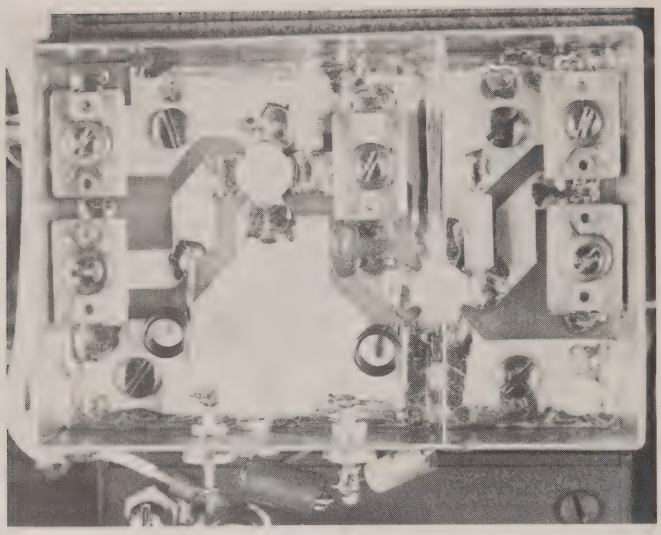


Figure 58

With the exciter-tripler chain operating adjust C1101 & C1102 for MINIMUM reflected power at the input SWR meter. Adjust C1103, C1106, & C1105 (in that order) for maximum output power indication . . . readjust C1101 for minimum input reflected power and then repeak power output by readjustment of C1103, C1106, & C1105. Power output indication should be about 12 W. When modulation is applied the RF power indication will drop since it is an average power indicator. However, since the modulator is clamped the peak sync tip power is constant regardless of the average power indication which will vary with the content of modulation.

The Video Modulator

In order to obtain constant sync tip power which is essential to good quality video reproduction at the receiver (avoiding background changes in the picture brightness due to picture APL) it is necessary to clamp the video signal. Clamping also assures maximum power being transmitted at sync level which helps to keep the receiver locked in when weak received signal conditions prevail.

The video modulator is shown in figure 59. The input video is terminated in 75 ohms by the combination of R1 & R2 which also provides level control. The input stage provides a low impedance drive to the sync tip clamping diode which is at the base of a high impedance stage made up of a very high Beta transistor Q3.

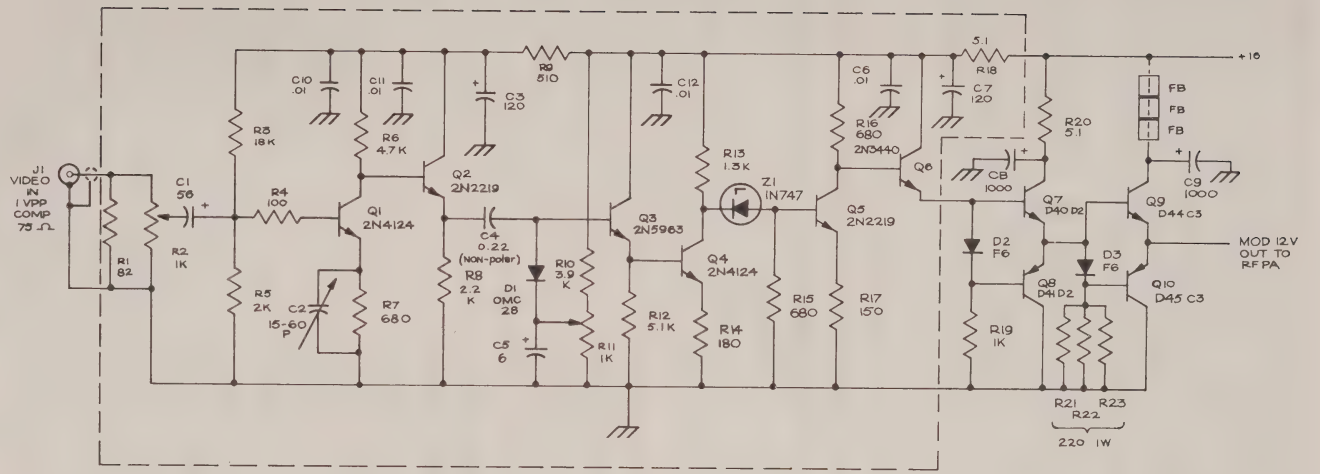


Figure 59

NOTE

1 Capaticance in Microfarads unless specified otherwise

2 Resistance in ohms ± 5% ½ W unless specified otherwise.

The following stages are direct coupled to preserve the DC restoration point and are designed to arrive at the correct operating point for the high level current modulation stage Q9-10 which is in series with the supply voltage to the final power amplifier. The current modulator provides a constant voltage source which is current modulated by the video signal thereby modulating the final stage of the power amplifier.

Since the final stages of the modulator dissipate substantial power these stages are mounted to a heat sink.

R11 sets the bias point of the clamp diode and thereby, through the DC coupled stages, the operating point of the final stage.

Testing Procedure

Before applying video adjust the clamp setting by using a voltmeter to measure and set the emitter of Q9 (Power amplifier current modulator) to 12 Volts by adjusting R11.

Apply a 1 V PP video (sync and picture), preferably a stairstep signal which can be a camera viewing a grey scale, to the video input.

Connect oscilloscope probe to base of Q9 (the video will be inverted, sync pos) and adjust R2 (input level pot) for a video level of about 4 V PP.

With the oscilloscope set for DC input, change picture content from black to white and observe sync tip DC level. If using a camera as video source view a white card and have someone block the lens intermittently. Proper operation will be indicated if no change in DC sync tip level is observed. To check for proper modulation level, use test setup in figure 59(a).

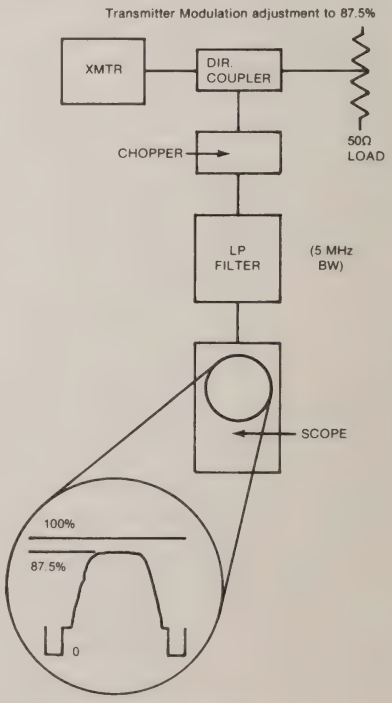


Figure 59(a)

The Aural Subcarrier Generator

Audio modulation for FSTV has taken two forms. One type uses a carrier located 4.5 MHz above the video carrier which is FM modulated (just like regular commercial TV), and the second method is to FM the video carrier with the audio modulation.

For equipment with limited video bandwidth, which is common to those items where a conversion of surplus equipment has been made for television use, a 4.5 MHz signal may not get through the system. If the transmitter has a bandwidth of only 2 or 3 MHz, naturally the 4.5 MHz carrier will be eliminated or severely attenuated. The video resolution is also poor.

In these cases modulation of the video carrier can be used. Referring to the exciter shown in figure 54 the microphone audio is switched to IC U1, and is amplified, rectified to produce a DC change which is then impressed on varactor D4 which FM's the exciter oscillator. It is important to RF decouple the input audio as shown.

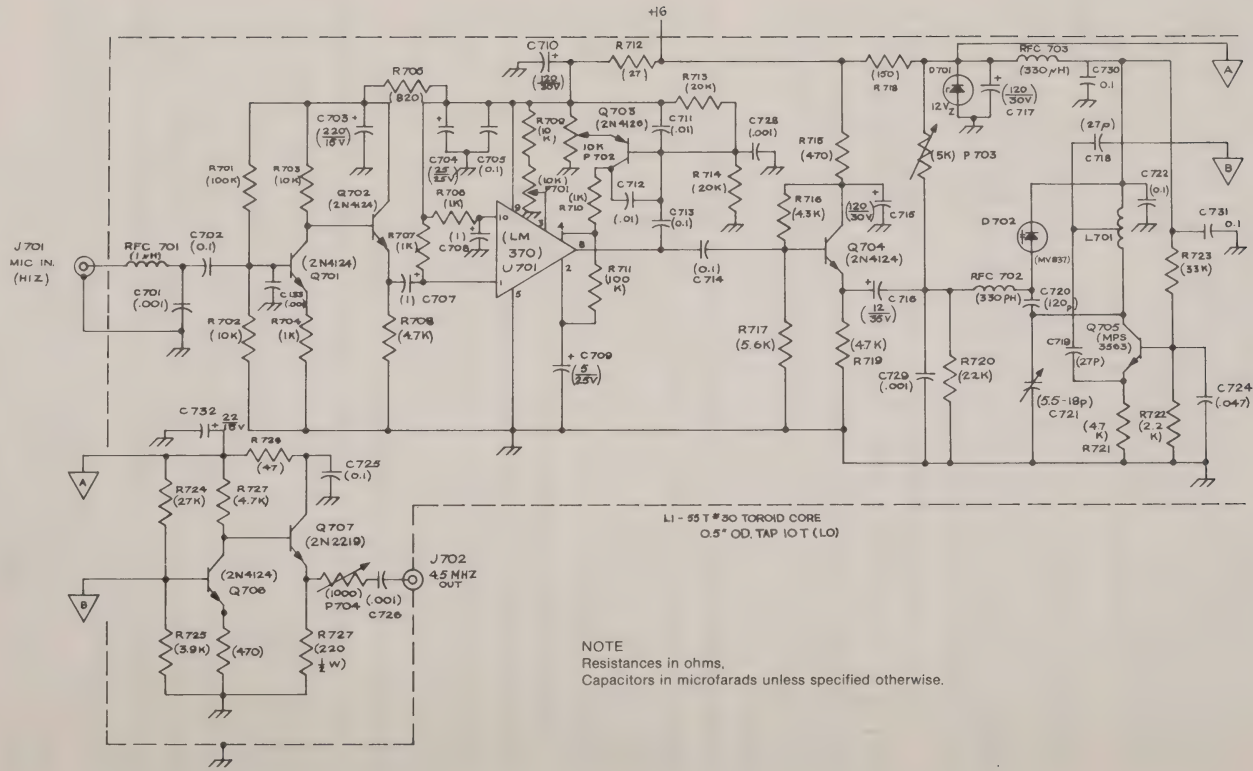
Reception of the audio by this type of audio transmission necessitates the use of a separate FM receiver operating at the video carrier frequency, or it is possible to insert a carrier in the TV set used at 41.25 MHz. In either case a standard TV set cannot be used without such carrier insertion or the special receiver must be employed.

This problem is eliminated by using 4.5 MHz subcarrier which is transmitted as part of the video signal and treated by the receiver as intercarrier audio just as it does in conventional TV broadcasts. It is also possible to use a separate audio transmitter which is diplexed at RF in the antenna which is what commercial TV broadcast stations do. This is expensive and not necessary for ATV.

The 4.5 MHz aural modulator shown in figure 60 consists of a microphone preamp, Q701 & Q702. U701 is an OP Amp providing AGC for the audio modulating signal thereby avoiding any possibility of over modulation. Q 703 is a peak detector which provides DC gain control to U701. Q705 is the audio subcarrier oscillator operating at 4.5 MHz. Q705 is FM modulated by varactor D 702. The audio signal varies the capacity of D 702 thereby frequency modulating the oscillator.

Q 706 & Q707 provide the driving power for insertion of the subcarrier energy which is passively mixed with the video at the input of the video modulator.

Since the 4.5 MHz subcarrier is passively mixed with the video it



NOTE
Resistances in ohms,
Capacitors in microfarads unless specified otherwise.

Figure 60

is possible for this energy to be present on any external monitoring system of the video such as when the camera video is looped through a monitor (of sufficient response) before terminating at the transmitter video input. The subcarrier is seen as a frequency beat on the monitor. To avoid this a low pass filter (construction details are shown elsewhere in this publication) can be placed in series with the coax feeding the transmitter video input. Since this filter has a cutoff at about 4 MHz the subcarrier energy is not present on the video coax.

The subcarrier PC board should be carefully grounded and shielded from other modules in the transmitter.

Testing Procedure

You will need a 400 Hz tone generator with an output level of -58 db and a 4.5 MHz frequency meter or calibrated HF receiver, along with a scope and voltmeter.

Connect the tone generator to the input (@ -58db level) and place scope probe at the emitter of Q704. Adjust P701 for .7 V PP then adjust P702 until peak-peak level just begins to drop. This sets AGC levels and if you change input level the scope presentation should now remain essentially the same as the level is increased.

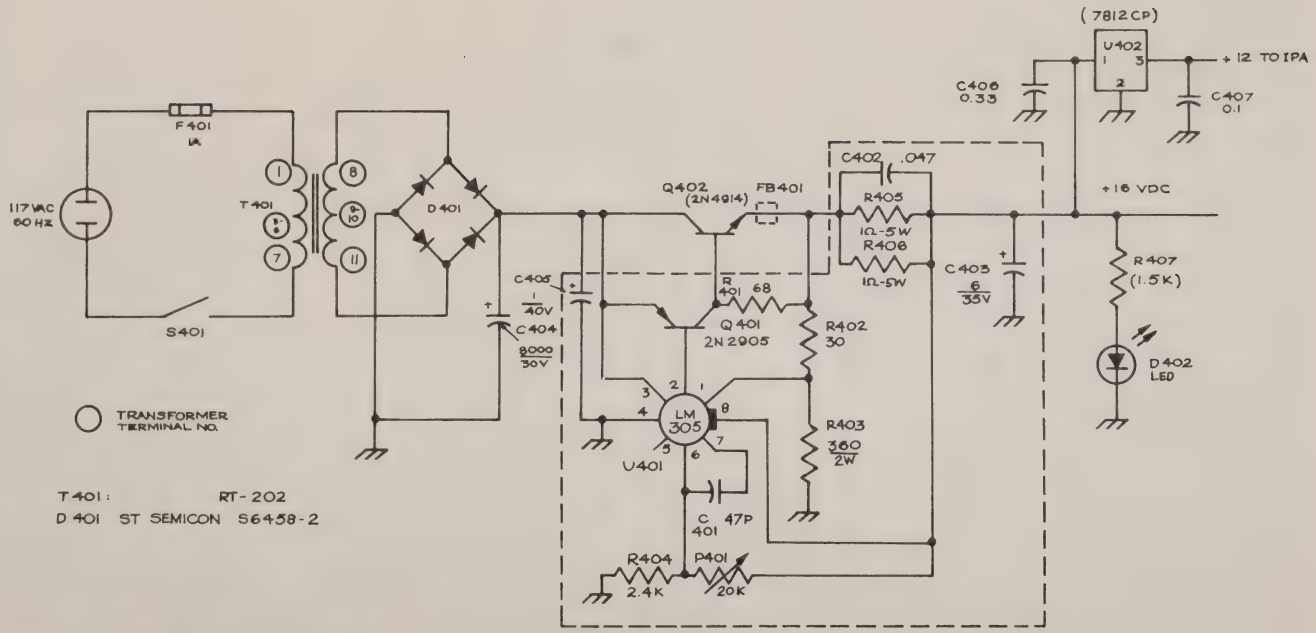
Now remove the tone input and couple the frequency meter or HF receiver to J702. Connect the scope probe to J702 and a DC voltmeter to the junction of P703 and R720. Adjust P703 for a 9.5 V DC level. Now adjust C721 until the 4.5 MHz carrier is measured on the frequency meter or heard on the receiver.

Viewing the scope presentation adjust P704 for 200 millivolts PP of 4.5 MHz carrier, or 20-25% level of detected video output from transmitter.

Power Supply

It is very important that the power supply be highly regulated to obtain good performance. Figure 61 illustrates the power supply used. Power to the final RF amplifier stage is fed through the video modulator output stages which provide the current modulation for the final. It is essential that the voltage remain constant with variations in picture APL over a wide current range. The transmitter requires about 2.5 amperes with all systems in use.

A bridge rectifier, D401 provides DC to the power regulator comprised of Q401, Q402, & U401. A separate regulator, U402, is used



NOTE:
Resistances in ohms, capacitors in microfarads unless specified otherwise.

Figure 61

for the intermediate power amplifier in the final. Careful attention should be given to lead lengths and layout of the regulator PC card and the associated components. Because of the very large filter capacitor, it is essential that the bridge rectifier be as specified or its electrical equivalent since there is a very high surge current requirement as the sytem is turned on.

Figure 62 is a photo of the power supply showing layout of parts.

General Consideration

At the frequencies used, coax connectors can exhibit 1 or more db of loss and a type N connector should be used at the output. The output relay should be a high quality coax relay to minimize losses.

When working at high RF frequencies the essential elements of good construction techniques center upon attaining good grounds and minimum component lead lengths. Disregard for basics will lead to equipment which will not work at all or very poorly. Other considerations are parts layout, high quality components designed for the frequencies used, and good shielding enclosures.

The use of lock washers, plating, etc., may also be required. Generally attention to the primary requirements will also produce aesthetically improved equipment as well.

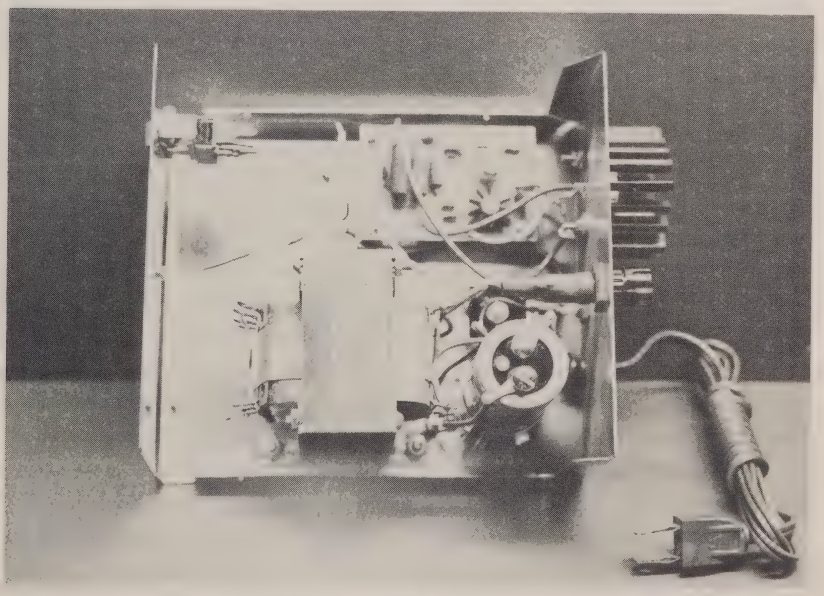


Figure 62

Television receiver/converter

The important factors for an ATV receiver are sensitivity, noise figure, and bandwidth. Acceptable reception for television pictures is somewhat subjective in that the noise manifests itself as 'snow' or white speckles in the received picture.

As a rule of thumb, pictures having S/N of approximately 26 db peak signal to RMS noise are considered to be 'minimum acceptable' pictures . . . such pictures have large speckles of noise superimposed on the picture and it is tiresome to watch. Since noise is a function of bandwidth, and the bandwidth of a TV signal is about 4 MHZ, it is important to measure noise with a low pass filter in the video circuit to limit the measurement of 4 to 5 MHz.

Noise figure is a term describing the figure of merit comparing the actual noise threshold of a receiver with a hypothetical noise-free receiver with the same bandwidth.

Mathematically the noise figure is expressed as the (output noise) of the receiver divided by the (the input noise times receiver gain). Or $F = N_0 / N_i \times G$. Usually the NF is expressed in db, thus $NF_{db} = 10 \log F$.

Noise figure is a complicated and difficult concept to discuss in a brief way and several references are given for the reader. (2, 4, 5). In recent years the term 'Noise Factor' has come into use and the method of measurement is slightly different from the traditional noise figure tests described in ref. (2).

The mere expression of noise figure is meaningless without specifying bandwidth. For example, two receivers with identical noise figure specifications but with different bandwidths would not be equivalent. The more narrow the bandwidth the better the performance should be as far as noise is concerned.

Another factor affecting good noise performance is the impedance matching precision at the input particularly. So regardless of the specified noise figure a poor antenna match will seriously degrade noise performance.

In the case of a television receiver system noise is manifested by 'snow' on the viewing screen and the acceptable level of 'snow' is physiologically different for different viewers, since it is a subjective phenomena without regard to the specified numeric value.

It is generally accepted that a video signal with a peak signal to RMS noise ratio of 26 db is a minimum acceptable signal . . . sync will hold but the picture is very noisy with snow. There is a 13 db

conversion between peak to peak noise and RMS noise (see ref. 4). Therefore, if a PP signal to PP noise is measured on an oscilloscope (the easiest for the amateur) as 20 db, the PP sig/RMS noise is 33 db.

Also as the S/N improves due to increased signal level at the receiver input the noise (snow) becomes increasingly more fine grain and less objectionable to the viewer. The eye can discern noise in a picture to about 52 db S/N, however, pictures with S/N's of 35 db are viewable for short periods.

When measuring S/N using an oscilloscope, one reads peak values. Be sure to make several measurements of the peak to peak noise since the apparent peaks of random noise vary substantially and are usually of low level . . . take an average reading of your several measurements. By setting the video signal level to a standard of one (1) volt peak to peak one can use the chart in figure 63 to determine PP signal to RMS noise of the picture. For example, is the video is set at 1 V PP and the apparent noise is measured at .22 V, the PP Sig/RMS noise is 26 db. The picture noise quality will improve rapidly with increased signal strength and become very acceptable at 40 db or so . . . less for some viewers . . . more for others.

The noise contributed by the receiver circuits is what needs to be controlled to as low a level as possible. Most of the noise will be due to the first RF amplifier stage in the receiver, which is then amplified further by the subsequent amplifier stages. There are other sources of noise in the receiver, but the first stage noise is the major contributor to noise figure performance of a receiver. When the received signal is very low level the first stage noise can be about the same level as the signal and the signal is lost in the noise. Device noise due to random electron currents are generally a function of collector or drain current amounts and thermal conditions of the

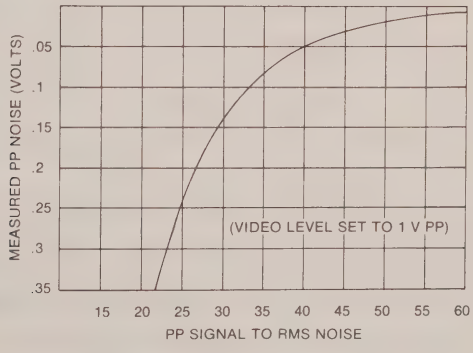


Figure 63

device. FET devices are generally better than bipolar devices, however there are many bipolar devices designed specifically for low noise contribution. Noise figures as low as 1 db to 5 db are typical for modern day devices.

With greater received signal strengths the level of receiver first stage noise relative to the received signal power makes the noise figure less important. For the same reason stages following the first stage see a larger level signal and the noise performance of the following stages are not as significant as that resulting in the first stage.

Conversely the more first stage noise the greater must be the received signal for the receiver to be able to discriminate the signal. Therefore, the receiver sensitivity will be improved as lower noise devices are employed (assuming other design factors are adhered to).

One of the most common ways amateur FSTV receivers are made is to downconvert the received signal to a VHF TV channel frequency so that any television set can be used as a 'monitor' rather than to demodulate to video. What is required is a receiver capable of receiving to 70 cm signal and downconverting to 55 to 60 MHz so that channel 2 or 3 of a standard TV set can be used as the monitor.

Most television UHF tuners (for economy reasons) have passive bandpass preselect and mixer cavities (i.e., no active device), use a diode mixer, and an oscillator stage. The RF, Mixer, and Oscillator stages are tuned together for the selection of different TV channels. The input RF signal energy is mixed with the oscillator energy in the diode mixer to produce an IF frequency which is then amplified by the TV receiver IF amplifier. The VHF tuner portion of the TV set is generally used as an IF amplifier preceding the regular IF amplifier of the TV set when the VHF selector is in channel 1 ('U') position which is required to use the UHF tuner.

Modern day UHF TV tuners have noise figures of 8 to 12 db. When such a tuner is modified to operate in the 70 cm band the noise figures will generally remain in this range, or perhaps degrade somewhat if the modification is poorly made.

A substantial improvement in performance can be had by preceding the tuner with an amplifier stage, preferably a bandpass amplifier designed to amplify the 420-450 MHz frequencies. Sensitivities of 2-5 uv with noise figures of 3-5 db are easily obtained in this way. If a single frequency device is designed, as for 439.25 MHz for example, even better performance can be obtained.

An ATV receiver for the 420-450 MHz Band

Reception of television signals require a broadband receiver to pass the high frequency video information contained in the picture. A minimum of 4 MHz bandpass is desirable. Since low power is the rule in transmission of ATV signals, the noise figure and sensitivity of the ATV receiver is of prime concern as well. Further, the propagation losses and terrain losses at UHF frequencies contribute to loss of signal strength at the receiver.

Some of these problems are offset by using high gain directional antennas which can be built relatively compactly at these frequencies, but when highly directional antennas are used some method for rotation must be used to allow pointing the antenna.

The receiver design discussed here is all solid state and is tunable over the entire band from 420-450 MHz.

Construction Techniques.

Figure 64 is a block diagram of the receiver. Figure 65 is a photograph showing the interior layout of the modules.

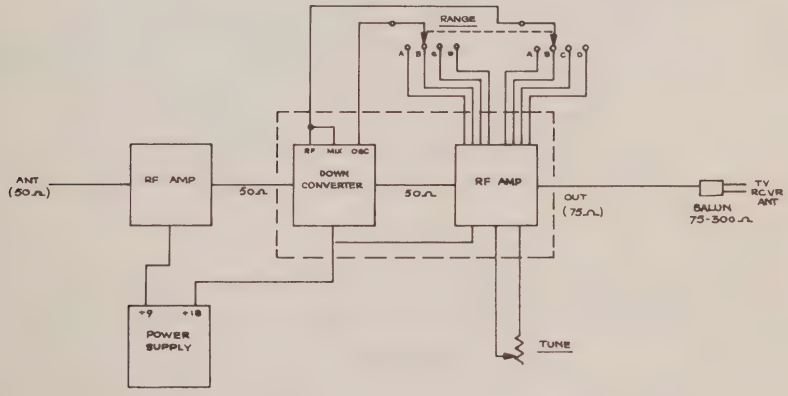


Figure 64

The bandpass preamp

Figure 66 is a schematic of the bandpass amplifier. The amplifier has a gain of about 10-12 db and a noise figure of approximately 3 db.

The PNP devices have best noise performance when operated at about 9V. By using a bandpass amplifier only the frequencies of interest are passed through the system and the gain of the preamp

1. P.S. Regulator Board
2. Band Pass Preamp
3. Downconverter (cover removed)
4. IF Amplifier

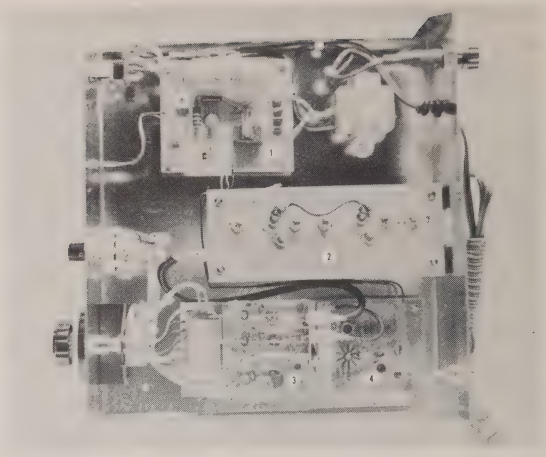
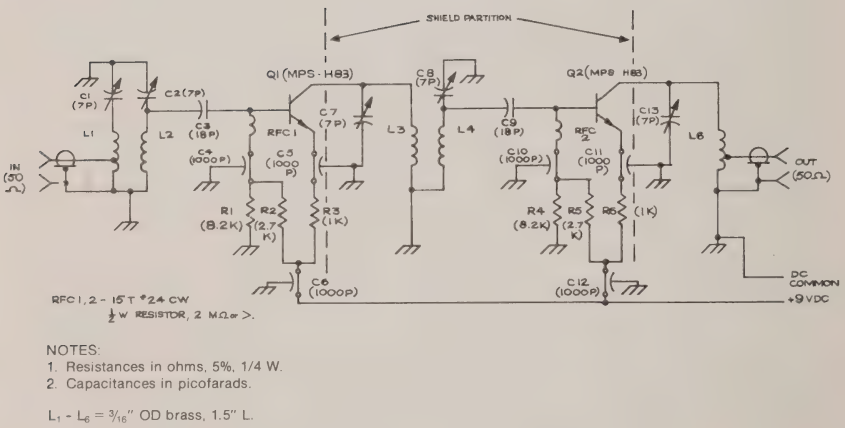


Figure 65



NOTES:
1. Resistances in ohms, 5%, 1/4 W.
2. Capacitances in picofarads.

$L_1 - L_6 = 3/16$" OD brass, 1.5" L.

Figure 66

diminishes the concern for the noise performance of the following downconverter allowing use of higher oscillator injection in the mixer diode which reduces the loss through the downconverter a little.

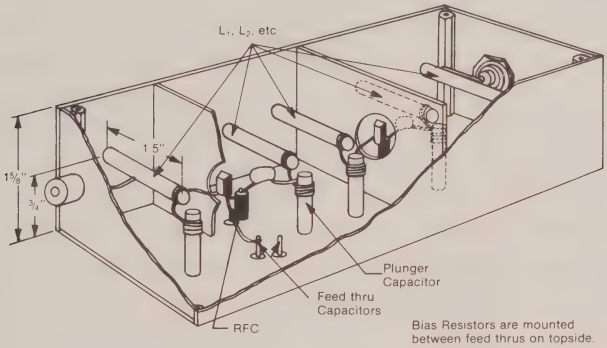
The input is tapped on the input tuned line a 50 ohms and the mechanical construction of the plunger type tuning capacitors and tuned lines give mutual mechanical support for simple construction. Figure 67 illustrates the construction of the bandpass preamp. There are two common emitter stages which can be tuned to give a

relatively flat topped response from 420-450 MHz. The output is directly tapped at 50 ohms and is connected through a short piece of 50 ohm coax to the downconverter module.

The Downconverter

The downconverter is a modified UHF tuner. The modification consists of removal of the tuning capacitor rotor blades and substitution of varactordiode tuning which is designed to allow use of potentiometers as the tuning control and to bring the frequency of operation into the 420-450 MHz band.

The first stage of the downconverter is a passive preselector RF section which is link coupled to the input. This stage is window coupled to the mixer section. The RF section and mixer section are tuned together from a common voltage source. The oscillator sec-



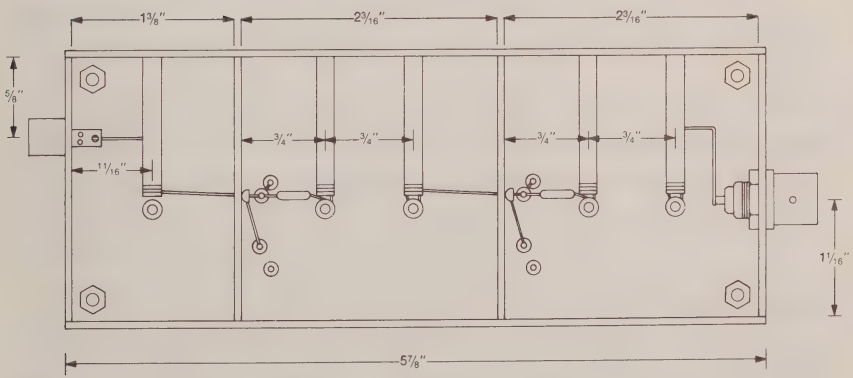


Figure 67

tion is coupled to the mixer via the diode mixer loop connection to the IF output connector which is located on the mixer section wall.

The modification requires that the tuning capacitor rotor bar and blades be removed and a button capacitor and varactor diode be soldered in series to ground. Voltage control to the varactor diode is connected at the junction of the button capacitor and varactor diode through an isolating resistor.

The unit is shown schematically in figure 68(a) and is mechanically mounted on the IF PC board where the range trimmer resistors are located. The tuning potentiometer is on the front panel along with the range selector switch.

As voltage is increased the varactor diode is reversed biased and the capacity of the diode decreases, hence the operating frequency increases.

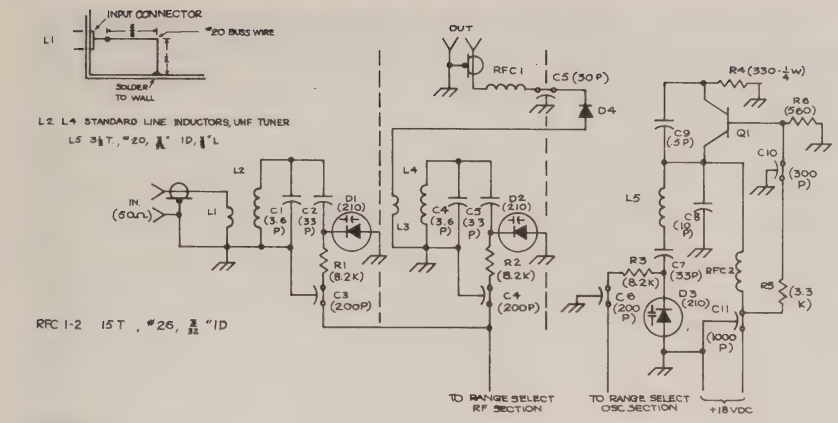
To bring the operating frequency of the UHF tuner into the 420-450 MHz range a small padding capacitor is soldered from the stator blade to ground in parallel with the seriesed button capacitor and varactor combination. The oscillator section will not generally operate reliably if a pad capacitor is used and will therefore require a slightly different tuning voltage to operate at the required frequency. However since the operating frequency of the oscillator is different from the input by the IF frequency it would be necessary anyway. Depending upon which make UHF tuner is used, the value of the padding capacitor may vary . . . the varactor and button capacitor should work without change.

The IF Amplifier

The IF amplifier shown in figure 68(b) utilizes a dual gate MOSFET device. The gain of this amplifier is approximately 25-30 db.

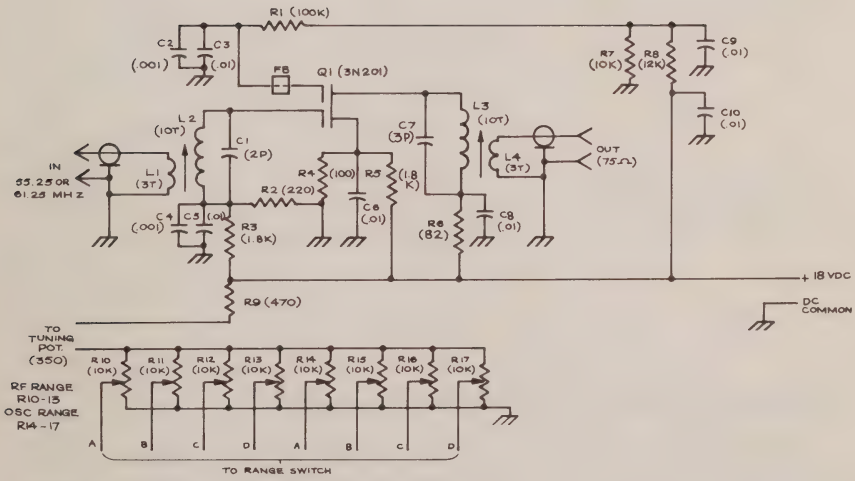
The input is link coupled to the converter output to provide a low resistance DC path for the mixer diode. The input and output tuned circuits are tuned to the desired IF, which can be either channel 2 or 3, by slug tuning of the coils.

The PC card for the IF amplifier is made longer than necessary to accommodate mounting the UHF tuner and the adjustment potentiometers. Tuning is accomplished by varying the DC voltage to the varactor diodes. Since the voltage range required for the oscillator section and mixer/RF sections is different to provide an IF of 55 to 60 MHz (ch 2 or 3) two separate range trimmer potentiometers



NOTES:
1. Resistances in ohms, 10%, 1/2 W unless specified otherwise.
2. Capacitances in picofarads.

Figure 68(a)



NOTES:
1. Resistances in ohms, 5%, 1/4 W unless specified otherwise.
2. Capacitances in microfarads unless specified otherwise.

Figure 68(b)

are provided. A potentiometer common to the source DC to the trimmer resistors is connected as a rheostat and varies the current through the trimmer pots which in turn varies the voltage to the varactors.

A range switch is used to allow vernier tuning over small sections of the band. In position 1, the tuning range is from 420 to about 430 MHz; in position 2, from 427 to 438 MHz; and position 3, from 435 to 445 MHz, and in position 4, from 438 to 450 MHz, (all ranges are approximate). Tuning in a station is greatly simplified if a vervier geared down drive is used for the tuning pot.

The Power Supply

The regulated power is straight forward using an IC regulator and a zener regulator to provide the 9V for the bandpass preamp. (See figure 69).

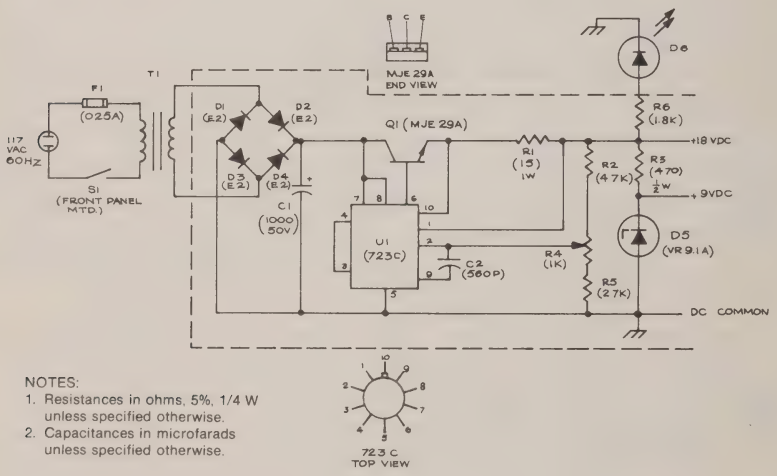


Figure 69

Directional Coupler for VSWR measurements

Figure 70 is a photo of a stripline design directional coupler. Figure 71 is a schematic of the unit. The unit must be mounted in an enclosure with dimensions as shown in figure 72. The unit is 50 ohms in and out. Figure 73 illustrates the response using as the unit is swept through 900 MHz.

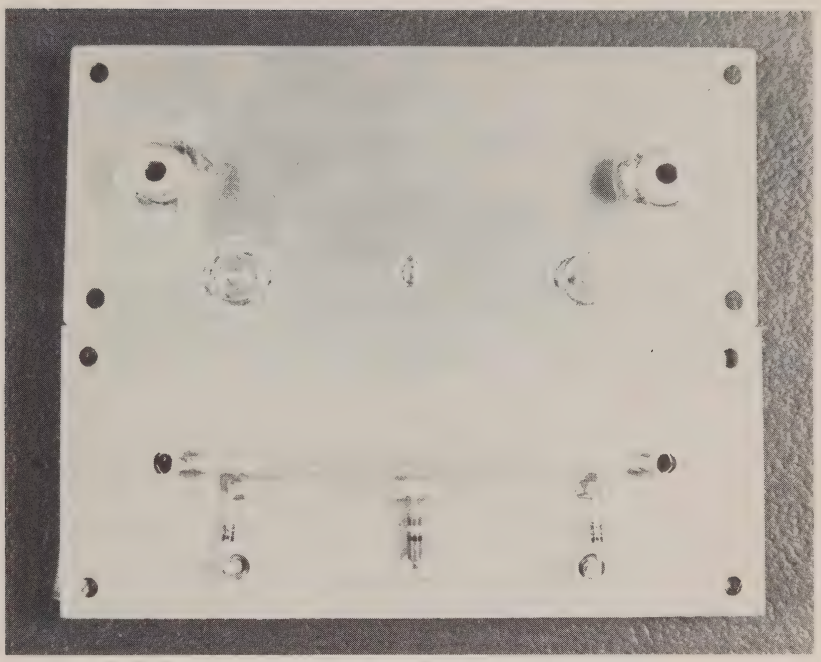


Figure 70

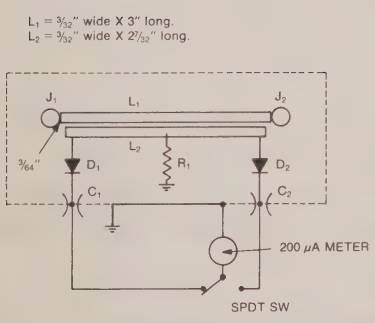
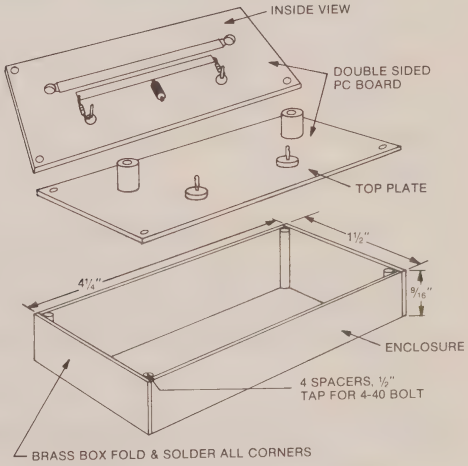


Figure 71



Parts list
R1, 22 ohm
D1, 2 IN34A
C1, 2 1000 pf feedthru
PC board (see dwg)
Enclosure (see dwg)
J1, 2 BNC

Figure 72

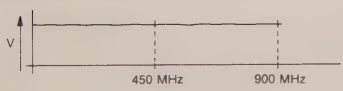


Figure 73

Video low pass filter

It is convenient to use a video low pass filter when making video response measurements to eliminate unwanted noise in the display. Figure 74 illustrates a low pass filter with a response as shown in figure 75.

The value of the capacitors is important and several capacitors may need to be used in parallel if standard available capacitors are used in the construction.

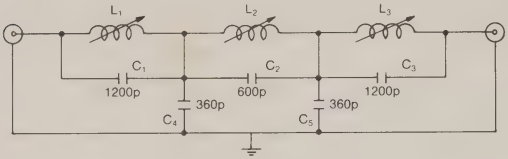


Figure 74

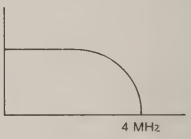


Figure 75

Parts List

L1, L3	11T #24 closewound, ¼ OD form, slug tuned.
L2	15T #24 closewound, ¼ OD form, slug tuned.
C1, C3	1200 pfd
C2	600 pfd
C4, C5	360 pfd.

Note: Enclose in shielded box.

Test Procedure

With sweep or TV multiburst generator connected to the input, terminate output in 75 ohms. View scope presentation adjust L1, L2, & L3 for flat response to 4 MHz & best attenuation above 4 MHz. (If using multiburst generator attenuation should begin on 4.2 MHz burst).

A 420 to 450 MHz Interdigital Bandpass Filter

Interdigital filters have the advantage of simplicity and very low insertion loss. Figure 76 illustrates a 420-450 MHz bandpass filter with an insertion loss of .5 db.

Construction details of the 420-450 MHz interdigital filter are shown in the following figures. Figure 77 is the response curve of the filter.

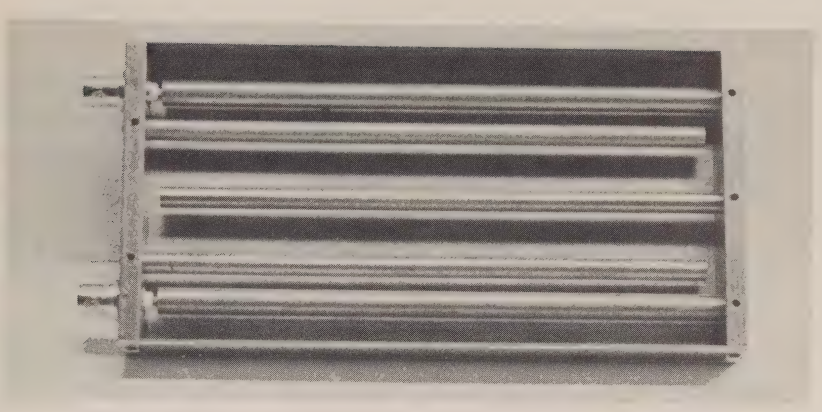
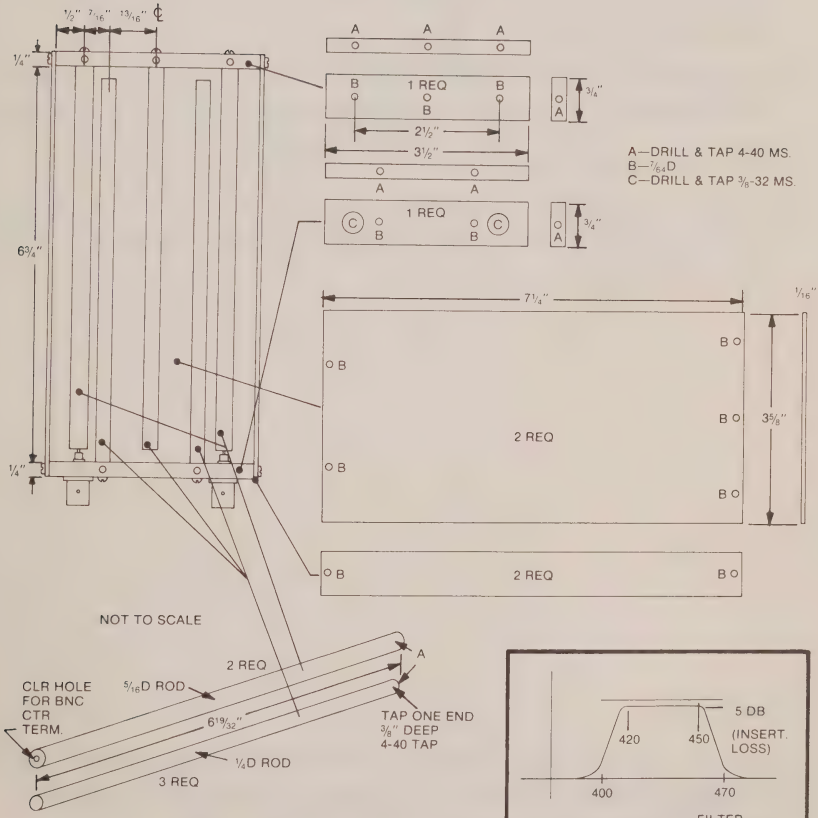


Figure 76



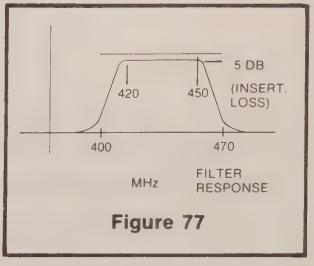


Figure 77

In construction, keep the following points in mind.

1) The ends of each bar must be flat and precise since the bars are supported by the 4-40 screw only and must be orthogonally aligned with the end pieces to be perfectly centered in the enclosure.

2) Drill clearance holes as precise as possible since the spacing of the bars to the top and bottom, as well as to each other is critical to good performance.

3) Sweat solder the BNC terminal carefully to the large end bars so that a good electrical connection is made without solder blobs.

4) Be sure the inside dimension of the structure is dimensioned as shown since this dimension assures that the end capacity of each bar is correct.

5) Test unit with all parts assembled as shown. You may leave off a side if necessary because the edge effect is minimal on the sides.

6) Either end may be used as input or output.

7) Clean brass should be used throughout. Plating is not necessary adding very little to the performance characteristics . . . and not worth the extra costs.

References:

1) Kraus, J. D. "Antennas", 1st Ed., McGraw Hill Book Co., 1950
2) Reference Data For Radio Engineers, 3rd Ed., 1949, pg. 463
3) NAB Engineering Handbook, 6th Ed., pg. 1086.
4) NAB Engineering Handbook, 5th Ed., pg. 4-81.
5) Procedures IRE, Vol. 32, July 1944, pg. 419-422.

CHARTS AND TABLES

Chart A

FREE-SPACE FIELD INTENSITY AND RECEIVED POWER BETWEEN HALF-WAVE DIPOLES.

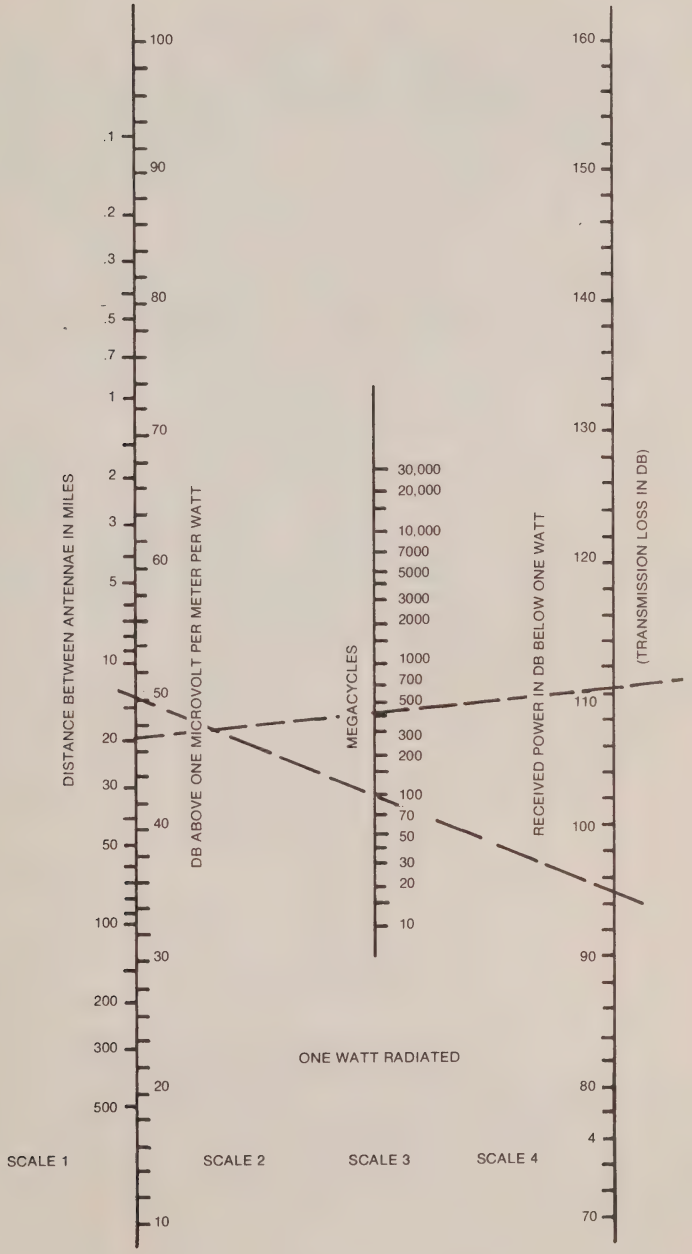


Chart B

DISTANCE VRS PICTURE SIZE GRAPH

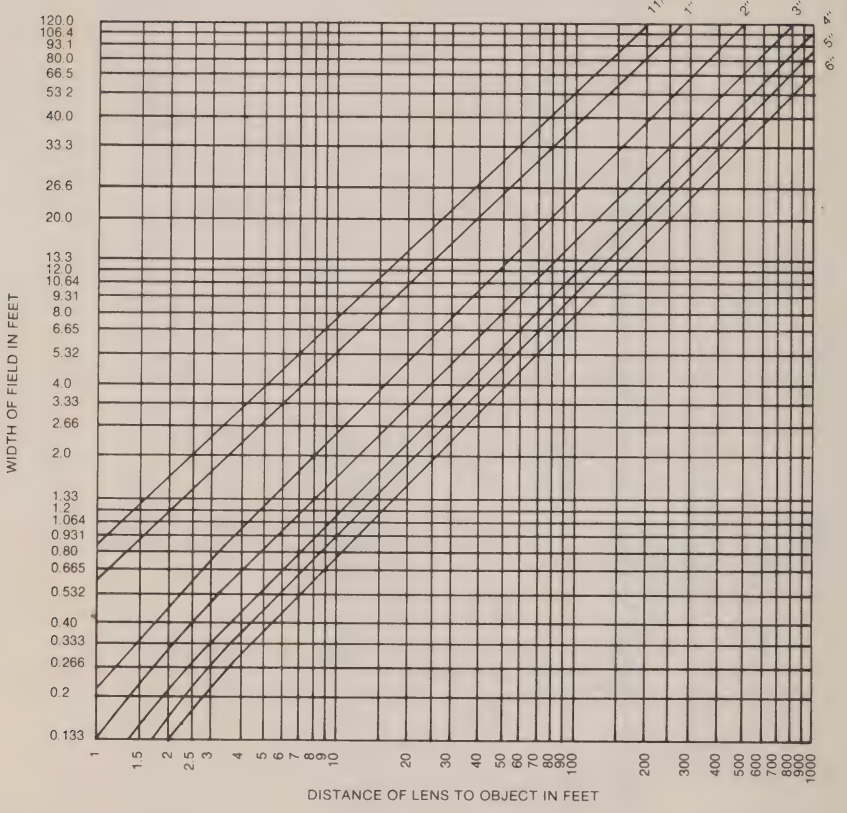
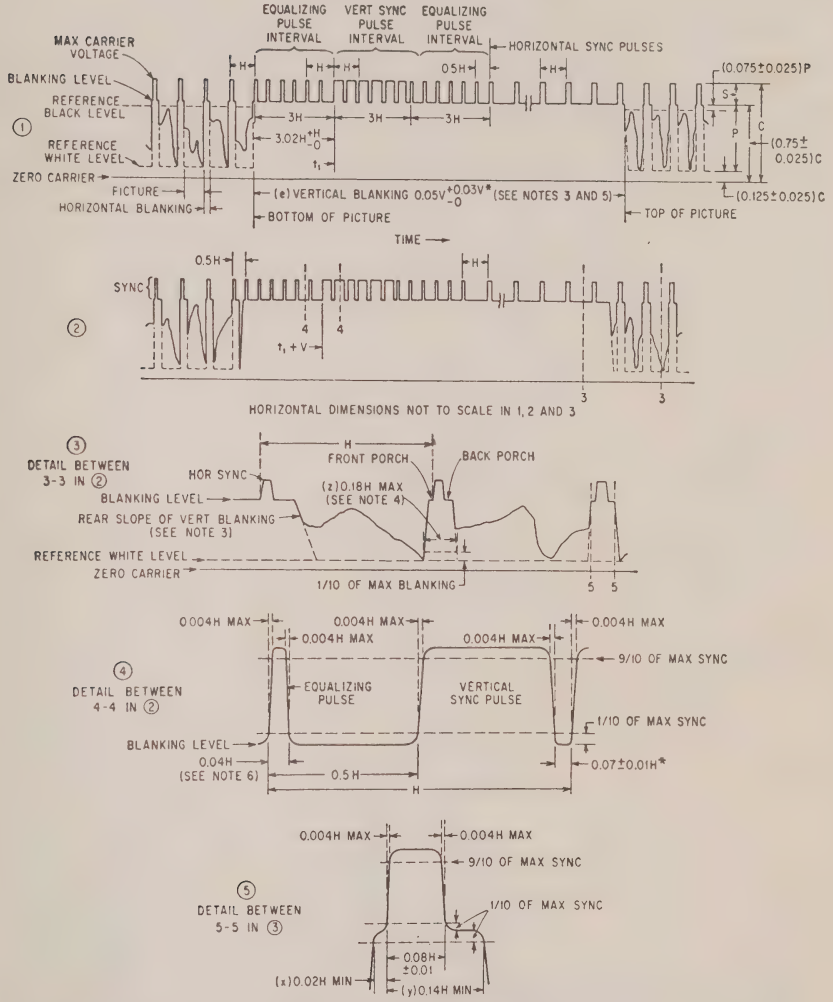


Table I*

FCC TELEVISION SYNCHRONIZING WAVEFORM FOR MONOCHROME TRANSMISSION ONLY.



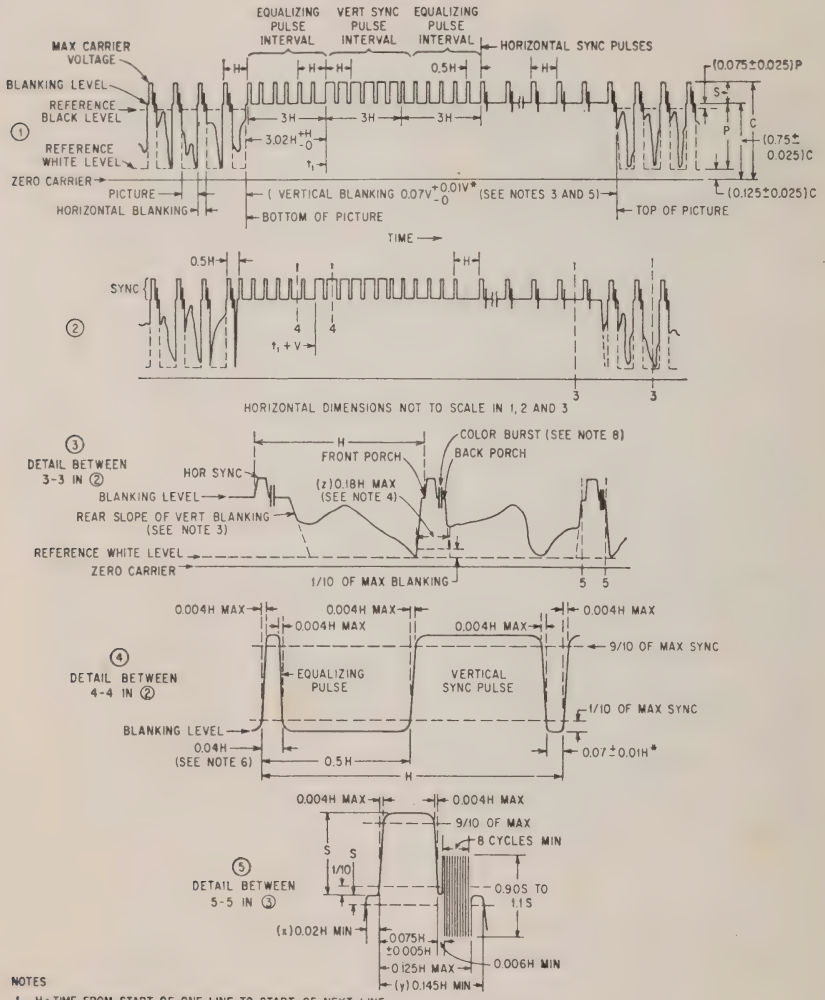
NOTES

1. H = TIME FROM START OF ONE LINE TO START OF NEXT LINE
2. V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD
3. LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H
4. LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x + y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT
- *5 DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES
6. EQUALIZING PULSE ARE SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE
7. REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

*From NAB Handbook

Table II*

TELEVISION SYNCHRONIZING WAVEFORM FOR COLOR TRANSMISSION.



NOTES

1 H = TIME FROM START OF ONE LINE TO START OF NEXT LINE.
2 V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD.
3 LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H.
4 LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x+y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT.
*5 DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES.
6 EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE.
7 COLOR BURST FOLLOWS EACH HORIZONTAL PULSE, BUT IS OMITTED FOLLOWING THE EQUALIZING PULSES AND DURING THE BROAD VERTICAL PULSES
8 COLOR BURSTS TO BE OMITTED DURING MONOCHROME TRANSMISSION.
9 THE BURST FREQUENCY SHALL BE 3.579545MC. THE TOLERANCE ON THE FREQUENCY SHALL BE ±10 CYCLES WITH A MAXIMUM RATE OF CHANGE OF FREQUENCY NOT TO EXCEED 1/10 CYCLE PER SECOND PER SECOND.
10 THE HORIZONTAL SCANNING FREQUENCY SHALL BE 2/455 TIMES THE BURST FREQUENCY.
11 THE DIMENSIONS SPECIFIED FOR THE BURST DETERMINE THE TIMES OF STARTING AND STOPPING THE BURST, BUT NOT ITS PHASE. THE COLOR BURST CONSISTS OF AMPLITUDE MODULATION OF A CONTINUOUS SINE WAVE.
12 DIMENSION "P" REPRESENTS THE PEAK EXCURSION OF THE LUMINANCE SIGNAL FROM BLANKING LEVEL, BUT DOES NOT INCLUDE THE CHROMINANCE SIGNAL. DIMENSION "S" IS THE SYNC AMPLITUDE ABOVE BLANKING LEVEL. DIMENSION "C" IS THE PEAK CARRIER AMPLITUDE
13 REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

*From NAB Handbook

Table III

SI PREFIXES

Facto	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

Table IV

SI DERIVED UNITS WITH SPECIAL NAMES

Quantity	SI Unit		
	Name	Symbol	Expression in Terms of Other Units
frequency	hertz	Hz	S^{-1}
force	newton	N	$kg \cdot m/s^2$
pressure, stress	pascal	Pa	N/m^2
energy, work, quantity of heat	joule	J	$N \cdot m$
power, radiant flux	watt	W	J/s
quantity of electricity, electric charge	coulomb	C	$A \cdot s$
electric potential, potential difference, electromotive force	volt	V	W/A
capacitance	farad	F	C/V
electric resistance	ohm	Ω	V/A
conductance	siemens	S	A/V
magnetic flux	weber	Wb	$V \cdot s$
magnetic flux density	tesla	T	Wb/m^2
inductance	henry	H	Wb/A
luminous flux	lumen	lm	$cd \cdot sr$
Illuminance	lux	lx	lm/m^2
Celsius temperature[1]	degree Celsius	°C	K
Activity (of a radionuclide)	becquerel	Bq	S^{-1}
Absorbed dose, specific energy imparted, kerma, absorbed dose index	gray	Gy	J/kg

Table V*

DECIBELS

Power ratio	Voltage or current ratio	—Db+	Voltage or current ratio	Power ratio	Power ratio	Voltage or current ratio	—Db+	Voltage or current ratio	Power ratio
10^{-1}		10		10	0.316	0.562	5.0	1.78	3.16
10^{-2}	10^{-1}	20	10	10^{2}	0.309	0.556	5.1	1.80	3.24
10^{-3}		30		10^{3}	0.302	0.550	5.2	1.82	3.31
10^{-4}	10^{-2}	40	10^{2}	10^{4}	0.295	0.543	5.3	1.84	3.39
10^{-5}		50		10^{5}	0.288	0.537	5.4	1.86	3.47
10^{-6}	10^{-3}	60	10^{3}	10^{6}	0.282	0.530	5.5	1.88	3.55
10^{-7}		70		10^{7}	0.275	0.525	5.6	1.91	3.63
10^{-8}	10^{-4}	80	10^{4}	10^{8}	0.269	0.519	5.7	1.93	3.72
10^{-9}		90		10^{9}	0.263	0.513	5.8	1.95	3.80
10^{-10}	10^{-5}	100	10^{5}	10^{10}	0.257	0.507	5.9	1.97	3.89
1.000	1.000	0	1.00	1.00	0.251	0.501	6.0	2.00	3.98
0.977	0.989	0.1	1.01	1.02	0.246	0.496	6.1	2.02	4.07
0.955	0.977	0.2	1.02	1.05	0.240	0.490	6.2	2.04	4.17
0.933	0.966	0.3	1.04	1.07	0.234	0.484	6.3	2.07	4.27
0.912	0.955	0.4	1.05	1.10	0.229	0.479	6.4	2.09	4.37
0.891	0.944	0.5	1.06	1.12	0.224	0.473	6.5	2.11	4.47
0.871	0.933	0.6	1.07	1.15	0.219	0.468	6.6	2.14	4.57
0.851	0.923	0.7	1.08	1.18	0.214	0.462	6.7	2.16	4.68
0.832	0.912	0.8	1.10	1.20	0.209	0.457	6.8	2.19	4.79
0.813	0.902	0.9	1.11	1.23	0.204	0.452	6.9	2.21	4.90
0.794	0.891	1.0	1.12	1.26	0.200	0.447	7.0	2.24	5.01
0.776	0.881	1.1	1.14	1.29	0.195	0.442	7.1	2.27	5.13
0.759	0.871	1.2	1.15	1.32	0.191	0.437	7.2	2.29	5.25
0.741	0.861	1.3	1.16	1.35	0.186	0.432	7.3	2.32	5.37
0.724	0.851	1.4	1.18	1.38	0.182	0.427	7.4	2.34	5.50
0.708	0.841	1.5	1.19	1.41	0.178	0.422	7.5	2.37	5.62
0.692	0.832	1.6	1.20	1.45	0.174	0.417	7.6	2.40	5.75
0.676	0.822	1.7	1.22	1.48	0.170	0.412	7.7	2.43	5.89
0.661	0.813	1.8	1.23	1.51	0.166	0.407	7.8	2.46	6.03
0.646	0.804	1.9	1.25	1.55	0.162	0.403	7.9	2.48	6.17
0.631	0.794	2.0	1.26	1.59	0.159	0.398	8.0	2.51	6.31
0.617	0.785	2.1	1.27	1.62	0.155	0.394	8.1	2.54	6.46
0.603	0.776	2.2	1.29	1.66	0.151	0.389	8.2	2.57	6.61
0.589	0.767	2.3	1.30	1.70	0.148	0.385	8.3	2.60	6.76
0.575	0.759	2.4	1.32	1.74	0.145	0.380	8.4	2.63	6.92
0.562	0.750	2.5	1.33	1.78	0.141	0.376	8.5	2.66	7.08
0.550	0.741	2.6	1.35	1.82	0.138	0.372	8.6	2.69	7.24
0.537	0.733	2.7	1.37	1.86	0.135	0.367	8.7	2.72	7.41
0.525	0.724	2.8	1.38	1.91	0.132	0.363	8.8	2.75	7.59
0.513	0.716	2.9	1.40	1.95	0.129	0.359	8.9	2.79	7.76
0.501	0.708	3.0	1.41	2.00	0.126	0.355	9.0	2.82	7.94
0.490	0.700	3.1	1.43	2.04	0.123	0.351	9.1	2.85	8.13
0.479	0.692	3.2	1.45	2.09	0.120	0.347	9.2	2.88	8.32
0.468	0.684	3.3	1.46	2.14	0.118	0.343	9.3	2.92	8.51
0.457	0.676	3.4	1.48	2.19	0.115	0.339	9.4	2.95	8.71
0.447	0.668	3.5	1.50	2.24	0.112	0.335	9.5	2.99	8.91
0.437	0.661	3.6	1.51	2.29	0.110	0.331	9.6	3.02	9.12
0.427	0.653	3.7	1.53	2.34	0.107	0.327	9.7	3.06	9.33
0.417	0.646	3.8	1.55	2.40	0.105	0.324	9.8	3.09	9.55
0.407	0.638	3.9	1.57	2.46	0.102	0.320	9.9	3.13	9.77
0.398	0.631	4.0	1.59	2.51	0.1000	0.316	10.0	3.16	10.00
0.389	0.624	4.1	1.60	2.57	0.0977	0.313	10.1	3.20	10.23
0.380	0.617	4.2	1.62	2.63	0.0955	0.309	10.2	3.24	10.47
0.372	0.610	4.3	1.64	2.69	0.0933	0.306	10.3	3.27	10.72
0.363	0.603	4.4	1.66	2.75	0.0912	0.302	10.4	3.31	10.96
0.355	0.596	4.5	1.68	2.81	0.0891	0.299	10.5	3.35	11.22
0.347	0.589	4.6	1.70	2.88	0.0871	0.295	10.6	3.39	11.48
0.339	0.582	4.7	1.72	2.95	0.0851	0.292	10.7	3.43	11.75
0.331	0.575	4.8	1.74	3.02	0.0832	0.288	10.8	3.47	12.02
0.324	0.569	4.9	1.76	3.09	0.0813	0.285	10.9	3.51	12.30

*From NAB Handbook

Table V* (continued)

DECIBELS

Power ratio	Voltage or current ratio	—Db+	Voltage or current ratio	Power ratio	Power ratio	Voltage or current ratio	—Db+	Voltage or current ratio	Power ratio
0.0794	0.282	11.0	3.55	12.59	0.0251	0.159	16.0	6.31	39.81
0.0776	0.279	11.1	3.59	12.88	0.0246	0.157	16.1	6.38	40.74
0.0759	0.275	11.2	3.63	13.18	0.0240	0.155	16.2	6.46	41.69
0.0741	0.272	11.3	3.67	13.49	0.0234	0.153	16.3	6.53	42.66
0.0724	0.269	11.4	3.72	13.80	0.0229	0.151	16.4	6.61	43.65
0.0708	0.266	11.5	3.76	14.13	0.0224	0.150	16.5	6.68	44.67
0.0691	0.263	11.6	3.80	14.45	0.0219	0.148	16.6	6.76	45.71
0.0676	0.260	11.7	3.85	14.79	0.0214	0.146	16.7	6.84	46.77
0.0661	0.257	11.8	3.89	15.14	0.0209	0.145	16.8	6.92	47.86
0.0646	0.254	11.9	3.94	15.49	0.0204	0.143	16.9	7.00	48.98
0.0631	0.251	12.0	3.98	15.85	0.0200	0.141	17.0	7.08	50.12
0.0617	0.248	12.1	4.03	16.22	0.0195	0.140	17.1	7.16	51.29
0.0603	0.246	12.2	4.07	16.60	0.0191	0.138	17.2	7.24	52.48
0.0589	0.243	12.3	4.12	16.98	0.0186	0.137	17.3	7.33	53.70
0.0575	0.240	12.4	4.17	17.38	0.0182	0.135	17.4	7.41	54.95
0.0562	0.237	12.5	4.22	17.78	0.0178	0.133	17.5	7.50	56.23
0.0550	0.234	12.6	4.27	18.20	0.0174	0.132	17.6	7.59	57.54
0.0537	0.232	12.7	4.32	18.62	0.0170	0.130	17.7	7.67	58.88
0.0525	0.229	12.8	4.37	19.05	0.0166	0.129	17.8	7.76	60.26
0.0513	0.227	12.9	4.42	19.50	0.0162	0.127	17.9	7.85	61.66
0.0501	0.224	13.0	4.47	19.95	0.0159	0.126	18.0	7.94	63.10
0.0490	0.221	13.1	4.52	20.42	0.0155	0.125	18.1	8.04	64.57
0.0479	0.219	13.2	4.57	20.89	0.0151	0.123	18.2	8.13	66.07
0.0468	0.216	13.3	4.62	21.38	0.0148	0.122	18.3	8.22	67.61
0.0457	0.214	13.4	4.68	21.88	0.0145	0.120	18.4	8.32	69.18
0.0447	0.211	13.5	4.73	22.39	0.0141	0.119	18.5	8.41	70.79
0.0437	0.209	13.6	4.79	22.91	0.0138	0.118	18.6	8.51	72.44
0.0427	0.207	13.7	4.84	23.44	0.0135	0.116	18.7	8.61	74.13
0.0417	0.204	13.8	4.90	23.99	0.0132	0.115	18.8	8.71	75.86
0.0407	0.202	13.9	4.96	24.55	0.0129	0.114	18.9	8.81	77.62
0.0398	0.200	14.0	5.01	25.12	0.0126	0.112	19.0	8.91	79.43
0.0389	0.197	14.1	5.07	25.70	0.0123	0.111	19.1	9.02	81.28
0.0380	0.195	14.2	5.13	26.30	0.0120	0.110	19.2	9.12	83.18
0.0372	0.193	14.3	5.19	26.92	0.0118	0.108	19.3	9.23	85.11
0.0363	0.191	14.4	5.25	27.54	0.0115	0.107	19.4	9.33	87.10
0.0355	0.188	14.5	5.31	28.18	0.0112	0.106	19.5	9.44	89.13
0.0347	0.186	14.6	5.37	28.84	0.0110	0.105	19.6	9.55	91.20
0.0339	0.184	14.7	5.43	29.51	0.0107	0.104	19.7	9.66	93.33
0.0331	0.182	14.8	5.50	30.20	0.0105	0.102	19.8	9.77	95.50
0.0324	0.180	14.9	5.56	30.90	0.0102	0.101	19.9	9.89	97.72
0.0316	0.178	15.0	5.62	31.62	0.0100	0.100	20.0	10.00	100.00
0.0309	0.176	15.1	5.69	32.36					
0.0302	0.174	15.2	5.75	33.11					
0.0295	0.172	15.3	5.82	33.88					
0.0288	0.170	15.4	5.89	34.67					
0.0282	0.168	15.5	5.96	35.48					
0.0275	0.166	15.6	6.03	36.31					
0.0269	0.164	15.7	6.10	37.15					
0.0263	0.162	15.8	6.17	38.02					
0.0257	0.160	15.9	6.24	38.90					

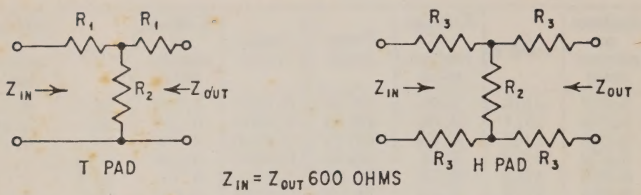
*From NAB Handbook

Table VI

PERCENTAGE LOSS VS. SWR

SWR	% Power Losses	SWR	% Power Losses
1-1	0%	3-1	25%
1.3-1	2%	4-1	38%
1.5-1	4%	5-1	48%
1.7-1	6%	6-1	55%
2-1	11%	10-1	70%

Table VII*
RESISTIVE PADS



$Z_{IN} = Z_{OUT}$ 600 OHMS

FOR IMPEDANCES OTHER THAN 600 OHMS,
MULTIPLY ALL RESISTORS BY FACTOR $\frac{Zx}{600}$

For impedances other than 600 ohms, multiply all resistors by factor $Zx/600$.

$Z_{in} = Z_{out}$ = 600 ohms

Loss	EIA resistor values *			Loss	EIA resistor values *		
	R_1	R_2	R_3		R_1	R_2	R_3
½	18	10,000	8.2	16	430	200	220
1	36	5,100	18	17	470	180	220
2	68	2,700	36	18	470	150	240
3	100	1,800	51	19	470	130	240
4	130	1,200	68	20	510	120	240
5	160	1,000	82	22	510	100	270
6	200	820	100	24	510	75	270
7	220	680	110	26	560	62	270
8	270	560	130	28	560	47	270
9	300	470	150	30	560	39	270
10	300	430	160	32	560	30	300
11	330	360	160	34	560	24	300
12	360	330	180	36	560	18	300
13	390	270	200	38	560	15	300
14	390	240	200	40	560	12	300
15	430	220	200				

* EIA resistor values nearest to the exact values are given.
*From NAB Handbook

Table VIII
COLOR VECTORS

Reference Burst	180°
-I	303°
Q	33°
Yellow	167°
Cyan	284°
Green	241°
Magenta	61°
Red	104°
Blue	347°

Table IX
COLOR FREQUENCIES

Color subcarrier	3.579545	Megahertz
½ H	31.468	kilohertz
Horizontal	15.734	kilohertz
Vertical	59.94	hertz

$6.50

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